Golder Associates Inc.

3730 Chamblee Tucker Road
Atlanta, GA USA 30341
Telephone (404) 496-1893
Fax (404) 934-9476

REPORT ON

LITTLE TUNNEL
STABILITY ASSESSMENT
CUMBERLAND GAP, TENNESSEE

Submitted to:

Vaughn & Melton Engineers
P.O. Box 1425
Middlesboro, Kentucky 40965

DISTRIBUTION:

5 Copies - Vaughn & Melton Engineers
2 Copies - Golder Associates Inc.

April 1995

953-3720

Golder Associates Inc.

3730 Chamblee Tucker Road
Atlanta, GA USA 30341
Telephone (404) 496-1893
Fax (404) 934-9476

April 12, 1995 953-3720

Vaughn & Melton Engineers
P.O. Box 1425
Middlesboro, Kentucky 40965

Attn: Mr. Lewis N. Melton

RE: REPORT ON LITTLE TUNNEL
STABILITY ASSESSMENT
CUMBERLAND GAP, TENNESSEE

Gentlemen:

We are pleased to submit this report on the recent rock fall and condition survey in Little Tunnel, Tennessee. The report discusses the design and comparative costs of several options for stabilizing the tunnel and the possibility of using the tunnel as a trail or bike path.

The selection of the method for stabilizing the tunnel should be made by the National Park Service as it will depend on the funds available, the need to construct a trail and the maintenance costs. These issues and the risks associated with each option for stabilizing the tunnel are discussed in the report. Please note that the cost estimates in this report are preliminary and should be reviewed by the FHWA who have more up-to-date, actual construction costs at Cumberland Gap.

If you or the FHWA or the NPS have any questions or comments on the report, please do not hesitate to contact us. I would like to express my thanks to the FHWA personnel at the Cumberland Gap Project Office and to David Robinson for useful discussion and input.

Very truly yours,

GOLDER ASSOCIATES INC.

Richard W. Humphries, P.E.
Senior Consultant and Principal

W. Randall Sullivan, P.E.
Program Director and Principal

W. RANDALL SULLIVAN
REGISTERED ENGINEER
AGRICULTURE
COMMERCE
No. 023294
STATE OF TENNESSEE

3720-RP5.B10\953-3720\JAJ

TABLE OF CONTENTS

1.0 INTRODUCTION

Little Tunnel is a 100 year old, disused railroad tunnel which crosses under the US25E/US 58 interchange between the towns of Cumberland Gap and Harrogate, Tennessee in the Cumberland Gap National Historic Park. The tunnel is currently used as a utility corridor for telephone cables, TV cable, power cable, water and sewer lines. The National Park Service is interested in evaluating whether the tunnel can be used as a trail and bike path connecting different areas of the park.

The tunnel is approximately 1,000 feet long. It is partially brick lined and partially lined with timber arches, or sets, and wooden lagging. In 1986, two timber sets collapsed causing a rock fall in the tunnel. Repairs and additional stabilization were done in 1987 and 1990.

One additional set collapsed in the timber lined section in 1994. To examine the cause of this collapse, Federal Highway Administration (FHWA) requested Vaughn & Melton and Golder Associates to review the stability of the tunnel. On January 25 and 26, 1995, Richard Humphries, of Golder Associates, and Don Slaven, of Vaughn & Melton, logged the condition of the timber sets, the repaired sections, and the brick lining, and discussed the technical aspects of the project with the members of FHWA at the Cumberland Gap Project Office.

The object of this report is to describe these stability conditions and to present options for stabilizing the tunnel so that it could be used as a trail and bike path. Design of the stabilization can proceed once the preferred option for stabilization is selected by National Park Service and FHWA.

2.0 EXISTING CONDITIONS IN LITTLE TUNNEL

The original excavated length of Little Tunnel was 1,034 feet. Two hundred and seventy feet from the west portal was brick lined and the remaining 758 feet was lined with 12 inch by 12 inch timber sets at four feet on centers with lagging between the timber sets. As part of the construction of US25E/US 58 interchange, approximately 200 feet has been added to the west end of the tunnel in the form of a covered, corrugated steel arch.

In 1986, Golder Associates logged the stability conditions in the tunnel and prepared designs for the repairs to the most critical sections of the tunnel. The report on the stability evaluation of the tunnel is presented in a report dated May 1986, which is attached to this report as Appendix A. The design drawings for the repairs to Little Tunnel and the as-built mark-ups are available in the FHWA office at the Cumberland Gap Tunnel Project. The tunnel log from the 1986 stability evaluation is given on Figure 3 of Appendix A. During the visit to Little Tunnel on January 25 and 26, 1995, the tunnel was relogged on the original logging sheet. This relogging is shown on Figure 2 of this report.

A description of the geology of the tunnel is given in Appendix A. The west end of the tunnel, above the brick lining, is a horizontally bedded shale unit of the Rockwood formation, while the eastern end of the tunnel, above the timber lined portion of the tunnel, is a sub-horizontally bedded limestone unit with occasional calcareous shale interbeds of the Sequatchie formation.

The brick lining in the tunnel is in excellent condition and there is no observable deterioration since the 1986 logging. However, the timber sets and wooden lagging in the remainder of the tunnel vary significantly from severely deteriorated to apparently solid and stable. In general, in this timber lined section of the tunnel, pieces of rock have broken loose from the original excavated tunnel section and are lying on the timber sets and lagging, as shown on Figure 1. The horizontal limestone beds have stoped up and appear to have formed a stable rock crown above the timber sets, with a void between the loose rock and the rock crown. The load of loose rock that is sitting on top of the timbers varies considerably. In places, it is severely overstressing the timber sets.

During the repairs to the tunnel in 1987, timber sets were removed at three locations. At each of these locations, the rock crown that remained after removal of the sets was stable, though the crown had stoped up to a maximum of about 12 feet above the top of the timber sets. The locations of the three repaired areas are shown on the log of the conditions in the tunnel on Figure 2. A similar stable crown can be seen above the zone that collapsed in the 1994 rock falls.

In general, there has been significant deterioration in the condition of the timbers in the tunnel over the nine years since the previous logging. Many of the timbers have rotted significantly and some of the timber sets are distorted from the load of the loose rock resting on top of them.

The log of conditions of the timber sets that is shown on Figure 2 is self explanatory. However, the following areas are of particular concern:

- ❑ Bays 164 through 176. In this zone, between two previously repaired zones, there has been significant deterioration of the timber and many of the sets are distorted from the load of the loose rock on top of the lagging. According to Don Slaven, who inspected the repairs in the two adjacent sections in 1987, there is approximately ten feet of loose rock resting on top of the wooden lagging and there is a void big enough for a man to pass through below the rock crown of the tunnel. This zone appears as though it could fail at any time.
- ❑ Bays 151 through 159. This zone of the tunnel is relatively wet and many of the timbers have deteriorated significantly since 1986. The area does not appear to be overstressed but the condition of the timbers indicates that failure could happen soon.
- ❑ Bays 132 through 138. Several of the legs and haunch members on the north side of the tunnel are severely deteriorated.
- ❑ Bays 112 through 115, Bays 83 through 88, Bays 72 through 77, Bays 52 through 54, Bays 44 through 47, Bays 18 through 22. All these zones have rotten timbers which have deteriorated significantly since the 1986 logging.

In addition to the zones described above, there are a number of smaller zones or particular members of a timber set that are rotten to varying degrees. The locations of these are shown on Figure 2.

3.0 1994 ROCK FALL

The crown and haunch members of set 68/69 failed in 1994, causing a rock fall onto the floor of the tunnel. The volume of rock that fell onto the tunnel floor is relatively small and is estimated at approximately five cubic yards. The failure appears to have occurred because the timber set decayed and the haunch members fell off the leg members of the set, and not because of a high loading on the set from loose rock above it. In this area of the tunnel, the rock crown has stoped up only about three feet and the adjacent timber sets are not heavily loaded. The rock in the crown of the tunnel appears to have formed a stable arch and is not in need of immediate repair.

While the rock fall at set 68/69 is not particularly big and has not caused any significant damage, the issue of concern is that this set was not logged as being deteriorated or distorted in the 1986 logging. In particular, there was no record suggesting that this and its neighboring timber sets were in any worse condition than other sets in the tunnel. From this, one can infer that other sets in the tunnel could deteriorate and collapse. We do not know of any low-cost technique for estimating and monitoring the deterioration of timbers. Lacking such assessment, it is not safe to assume that any zone of the tunnel is stable and safe.

4.0 REPAIRS AND STABILIZATION IN 1987 AND 1990

Six zones in the timber lined section of the tunnel were stabilized or strengthened in 1987 and 1990. Details of these repairs are given in the As-Built Drawings which are in the FHWA office at Cumberland Gap. Two different types of stabilization and strengthening were used. These are:

- Bays 177 through 189, Bays 160 through 163 and Bays 105 and 106. Soon after the initial logging of the tunnel in February 1986, the zone from Bays 184 through 187 collapsed and deposited a large pile of loose rock and timber on the floor of the tunnel. During the repairs of this collapsed zone, the adjacent timber sets, between the west end of the brick lining (next to Bay 189) through to Bay 177, were removed along with the loose rock that the sets were supporting. At the same time the sets between Bays 160 and 163 and between Bays 105 and 106 were removed. The rock crown above these removed zones was scaled and rockbolted with ten foot long rockbolts at approximately four feet on centers. This work was done in 1987. Over the next three years there was some loosening and slaking of the rock around the newly installed rockbolts so, as part of the main Cumberland Gap Tunnel Construction Contract, two to three inches of shotcrete was placed on the crown of the tunnel in these three zones. At present, all three zones appear to be in good condition. There is no indication of cracking or distress in the shotcrete though there are a few minor drips around Bays 180 to 182, which is of no structural concern.
- Bays 42 and 43, Bays 23 and 24, and Bays 1 through 12. There is limited cover at the east portal of the tunnel. In 1986, there was a surface sinkhole above Bays 8 through 11 and it was considered unlikely that there was sufficient rock cover to form a stable arch for rockbolting and shotcreting. Consequently, the zone from Bays 1 through 12 was strengthened by constructing a reinforced concrete structure between each of the existing timber sets and leaving the timber sets in place. The same type of strengthening was used for Bays 23 and 24 and Bays 42 and 43. This type of strengthening appears to have worked well. Apparently, it was felt at the time that this type of strengthening is more expensive and time consuming than removing the timber sets and rockbolting and shotcreting the rock crown of the tunnel.

At the same time that this strengthening work was done in 1987, additional lagging was installed in many of the bays where the previous lagging was deteriorated or missing. In addition, set 166/167 was strengthened in the crown. During the logging of the tunnel in January 1995, the state of the lagging was not recorded because it is considered that the main cause for concern for the stability of the tunnel is dependent on the condition of the timber sets rather than the lagging.

5.0 OPTIONS FOR STABILIZING THE TUNNEL

There are seven possible options that can be considered for stabilizing and strengthening Little Tunnel. Each of these options has a different capital cost, maintenance costs, and risks to the public and maintenance workers who may be in the tunnel. In addition, some of these options could allow the tunnel to be used as a trail or bike path.

Preliminary comparative cost estimates for stabilizing and strengthening the tunnel and for annual maintenance have been prepared for each option. The brick lined section, the corrugated metal cut-and-cover section, and the sections at the east and west ends of the timber line section that were previously stabilized are considered to be stable and not in need of further work.

The options that could be considered for Little Tunnel are as follows:

5.1 Option 1 - Do Nothing Option

As mentioned previously, the rock fall that occurred in 1994 has not left the tunnel in a critically unstable condition. Progressive collapse is not expected in this zone and the volume of material from the rock fall is relatively small. Consequently, there is no pressing need to clean up or stabilize this section of the tunnel. Indeed, if it is not essential to use the tunnel as a utility corridor or for a future trail, it would be feasible to do nothing in the tunnel. There has been significant deterioration in the condition of the timber sets since 1986, and it is likely that there will be successive rock falls in the tunnel as the timber sets deteriorate further. However, even if there were to be a number of collapses of various areas of timber sets, it is likely that the crown of the tunnel has formed a stable arch in its present configuration and this arch will probably not collapse progressively and stope to the surface within the lifetime of the Cumberland Gap project.

If it is decided to select this "do nothing" option, it would be advisable to remove the telephone and TV cables that are attached to the walls of the tunnel, as they may be damaged during future rock falls. These cables could be installed in conduits which could be buried in the crushed stone invert of the tunnel. The utility companies should not then be allowed access to the buried conduits in the tunnel once they are installed. The same applies to the electric, sewer and water pipes in the invert of the tunnel. If this option is selected, it will be essential to keep all personnel out of the tunnel except those who are experienced in tunneling and understand the stability concerns of going into the tunnel.

The cost of this option is approximately $10,000 for reinstallation of the TV and telephone cables. There should be no maintenance.

5.2 Option 2 - Repair Collapsed Zone and Stabilize Worst Areas

As mentioned previously, there are a number of zones in the tunnel where the timber sets are severely deteriorated and/or overstressed. These zones are in imminent danger of collapse and need to be repaired if the tunnel is to continue to be used as a utility corridor with access for utility maintenance. The most economical way of repairing these zones would be to remove the timber sets in these specific areas and stabilize the crown by installing rockbolts and shotcrete in a similar way to the previous repairs.

The estimated cost to these repairs is $229,100 and it is estimated that there would be an on-going need for repairs as sets deteriorate and collapse. The estimated maintenance cost are estimated at approximately $30,000 per year. Even if these repairs were to be carried out, there is still a risk that other sets would collapse at any time and, consequently, it is not recommended that the tunnel be used for a trail or a bike path by use by the public. Further, the condition of the tunnel should be examined by an engineer experienced in tunnel stability before utility maintenance personnel enter the tunnel.

5.3 Option 3 - Install Corrugated Metal Pipe

A simple method of providing a safe trail or bike path through the tunnel would be to install a, thick-walled corrugated metal pipe through the timber lined section of the tunnel, as shown on Figure 3. This pipe would be similar to the corrugated metal pipe that was constructed to extend the tunnel at the west portal. These corrugated metal pipes are off-the-shelf items which can be installed very rapidly.

It will be necessary to place backfill above the pipe to provide a cushion in the event of future roof falls. Access to the space above the pipe is very limited so placing the backfill will be difficult.

The estimated cost of this option is $351,600 and there should be no maintenance costs.

5.4 Option 4 - Remove all Timber Sets: Shotcrete and Rockbolt Crown of Tunnel

This option would involve removing all of the remaining timber sets and rockbolting and shotcreting the rock crown of the tunnel. This method of stabilizing the tunnel worked well during the 1987 and 1990 repairs and is shown on Figure 4. The initial cost is estimated to be approximately $403,000 and there would be no maintenance cost. It would be necessary to investigate the rock conditions at the east end of the tunnel to ensure that there is sufficient rock cover to install rockbolts in the crown of the tunnel. With this option, it would be possible for the tunnel to be used as a trail or bike path and to have its continued use as a utility corridor.

5.5 Option 5 - Construct Concrete Structures in Bays Between Timber Sets

This method would involve constructing reinforcing concrete beams and columns between the existing timber sets using the same design as the previous repairs at the east end of the tunnel. This repair work was found to be relatively slow and would be dangerous as it would be necessary to work around the existing timber sets, some of which are likely to collapse at any time. It is estimated to be more expensive than the shotcrete and rockbolt option (Option 4) and would not be quite as stable as the existing sets would be left in place and may rot out completely over time. The tunnel could be used for a trail or bike path if this option were selected, but it would require periodic inspection of the timber sets to ensure that they have not completely rotted through. The estimated cost of this option is $463,000 and there would probably be no maintenance cost.

5.6 Option 6 - Backfill Tunnel

It will be possible to completely backfill the tunnel with soil or rockfill. This would be relatively inexpensive (estimated at $122,000) and would be maintenance free. However, the tunnel could not be used for a trail or bike path and there would then be no access to the utilities through the tunnel. As with Option 1, the TV and telephone cables could be placed in conduits in the invert of the tunnel.

The preliminary comparative cost estimates for each option are presented in Table 1. The capital cost estimates are based on calculated quantities and unit rates from similar work on the Cumberland Gap Project. The maintenance costs are less certain and are based on our judgment of the frequency that rock falls would occur in the tunnel and the need for repairs after each rock fall. Table 2 shows a comparison of the different options with their estimated initial capital costs, estimated maintenance costs, relative risks and the possibility of using the tunnel as a trail. The costs of lighting, paving, signposting, bicycle facilities, etc., have not been included in the cost estimates given for each option.

TABLE 1
COST ESTIMATES

OPTION 1 - DO NOTHING

Initial Capital Cost — Est. $10,000

Installation of telephone and TV cables in conduits in invert of tunnel

Maintenance Costs not required $0/year

OPTION 2 - REPAIR COLLAPSED ZONE AND STABILIZE WORST AREAS

Initial Capital Cost

- Length to be stabilized:

Bays 18 - 22	=	5'x4'	=	20'
Bays 30 - 33	=	4'x4'	=	16'
Bays 52 - 54	=	3'x4'	=	12'
Bays 67 - 93	=	27'x4'	=	108'
Bays 112 - 115	=	4'x4'	=	16'
Bays 132 - 138	=	7'x4'	=	28'
Bays 147 - 159	=	13'x4'	=	52'
Bays 164 - 176	=	13'x4'	=	52'
				304'

- Debris removal and set demolishing
  est. 18' wide x 5' x 304' = 1013 yd^3 at \$20/yd^3 = $20,260

- Rockbolts
  10' rockbolts: 5 across crown + 2 in. sidewalls every 4 ft.
  = 7x (304'/4) x 10' = 5,320 lin. ft. at $12/ft = $63,840

- Shotcrete
  3" thick (ave.) over 304' x 25' + 25% rebound
  = 70 yd^3 + 25% say 90 yd^3 at \$700/yd^3 = $63,000

- Mobilization
  est. at 15% $22,000

- Engineering and Construction Management
  est. $60,000

Est. Capital Cost $229,100

Maintenance Cost
Est.: 1 roof fall every 5 years at $150,000 for repairs average = $30,000/year

OPTION 3 - INSTALL CORRUGATED PIPE BACKFILL TUNNEL

Initial Capital Cost

- 2/3 circumference of 13.5 ft. diameter, thick-walled, corrugated metal pipe, 700 ft. long	$200,000
- Concrete Footing:	
2 sides 18" x 12", 700 ft. long = 76 yd^3 at $350	$26,600
- Backfill above pipe:	
1,500 yd^3 x $40	$60,000
Reinstall TV and electric cables	$5,000
- Mobilization	
est. at 15%	$40,000
- Engineering and Construction Management	
est.	$20,000
Est. Capital Cost	$351,600

Maintenance

None required $0/year

OPTION 4 - REMOVE ALL TIMBER SETS. SHOTCRETE AND ROCKBOLT CROWN OF TUNNEL.

Initial Capital Cost

- Length to be stabilized = Sta. 17+04 to Sta. 10+46
  minus (15'+7'+7'+7') already stabilized = 622'

- Debris removal and set demolishing		
est. 18' x 5' x 622' = 2073 yd^3 at $20/yd^3 =	$41,500	
- Rockbolts		
10' rockbolts: 5 across crown and 2 in sidewalls at 4' on centers		
= 7 x (622/4) x10 = 10,885 lin. ft. at $12/ft. =	$130,620	
- Shotcrete		
3" thick (ave.) over 622' x 25' +25% rebound		
= 144 yd^3 +25% = 180 yd^3 at $700/yd^3 =	$126,000	
- Mobilization	$45,000	
- Engineering and Construction Management est.	$60,000	
Est. Capital Cost		$403,120
Maintenance Cost None required		$0/year

OPTION 5 - CONSTRUCT CONCRETE STRUCTURES IN BAYS

Initial Capital Cost

- Length to be strengthened: Same as Option 5 = 622' or 141 bays

- Concrete:	141 bays x 3' wide x 15" thick x 50' circumference = 979 yd^3 say 1,000 yd^3 with footing x \$350/yd^3 including reinforcing, framework and access =	\$350,000	
- Mobilization	est.	\$53,000	
- Engineering and Construction Management	est.	\$60,000	
	Est. Capital Cost =		\$463,000

Maintenance Cost

	None Required	\$0/year

OPTION 6 - BACKFILL TUNNEL

Initial Capital Cost

- Length to be backfilled is length of existing timber sets = 700 ft. (approx.)

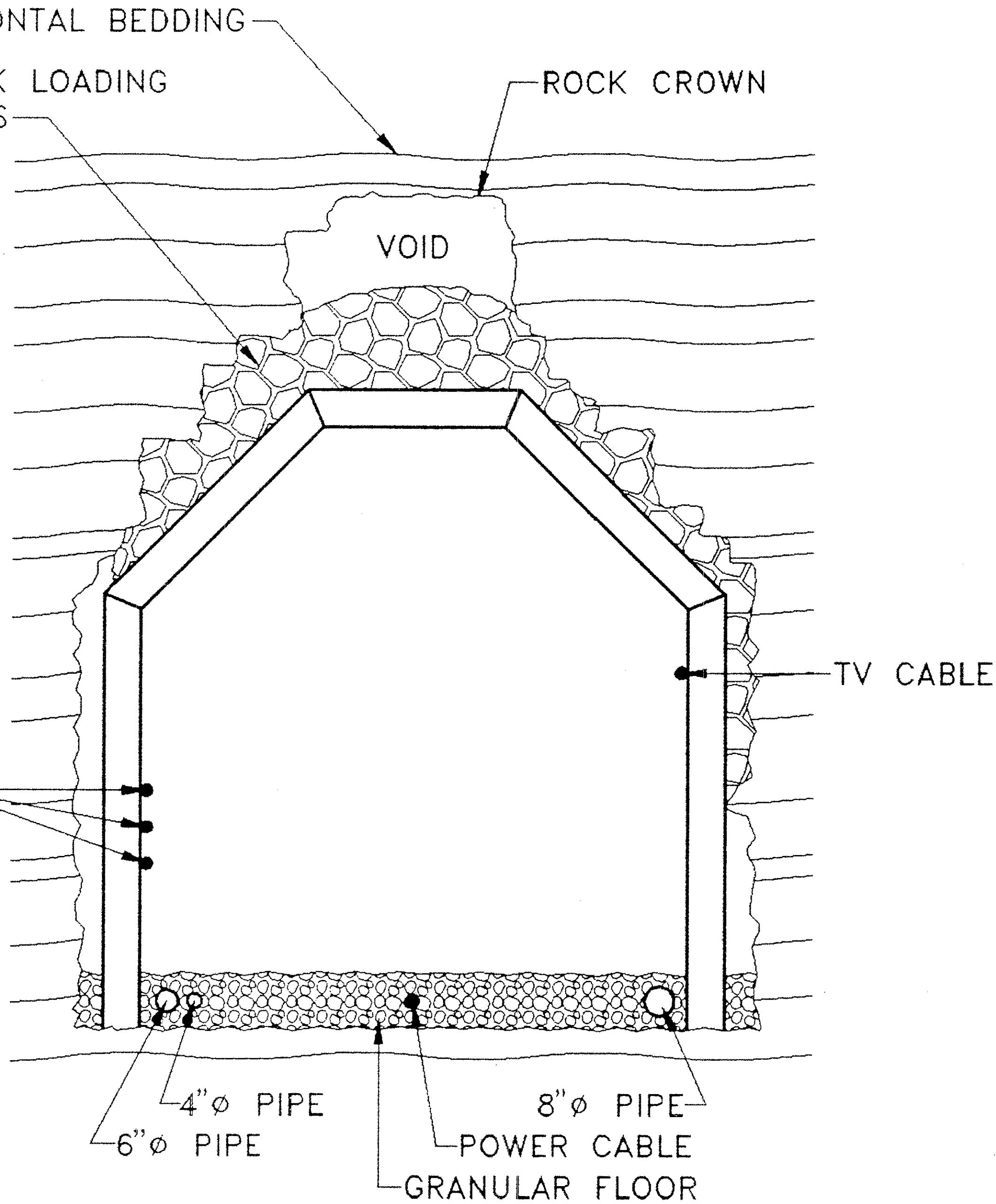
- Volume of backfill to 16' wide x 18' high x 700 ft. = 7,500 yd^3 at \$12/yd^3 =	\$90,000	
- Reinstall telephone and TV cables in conduits	\$10,000	
- Mobilization (est.)	\$12,000	
- Engineering and Construction Management (est.)	\$10,000	
Est. Capital Cost =		\$122,000

Maintenance Cost

	None Required	\$0/year

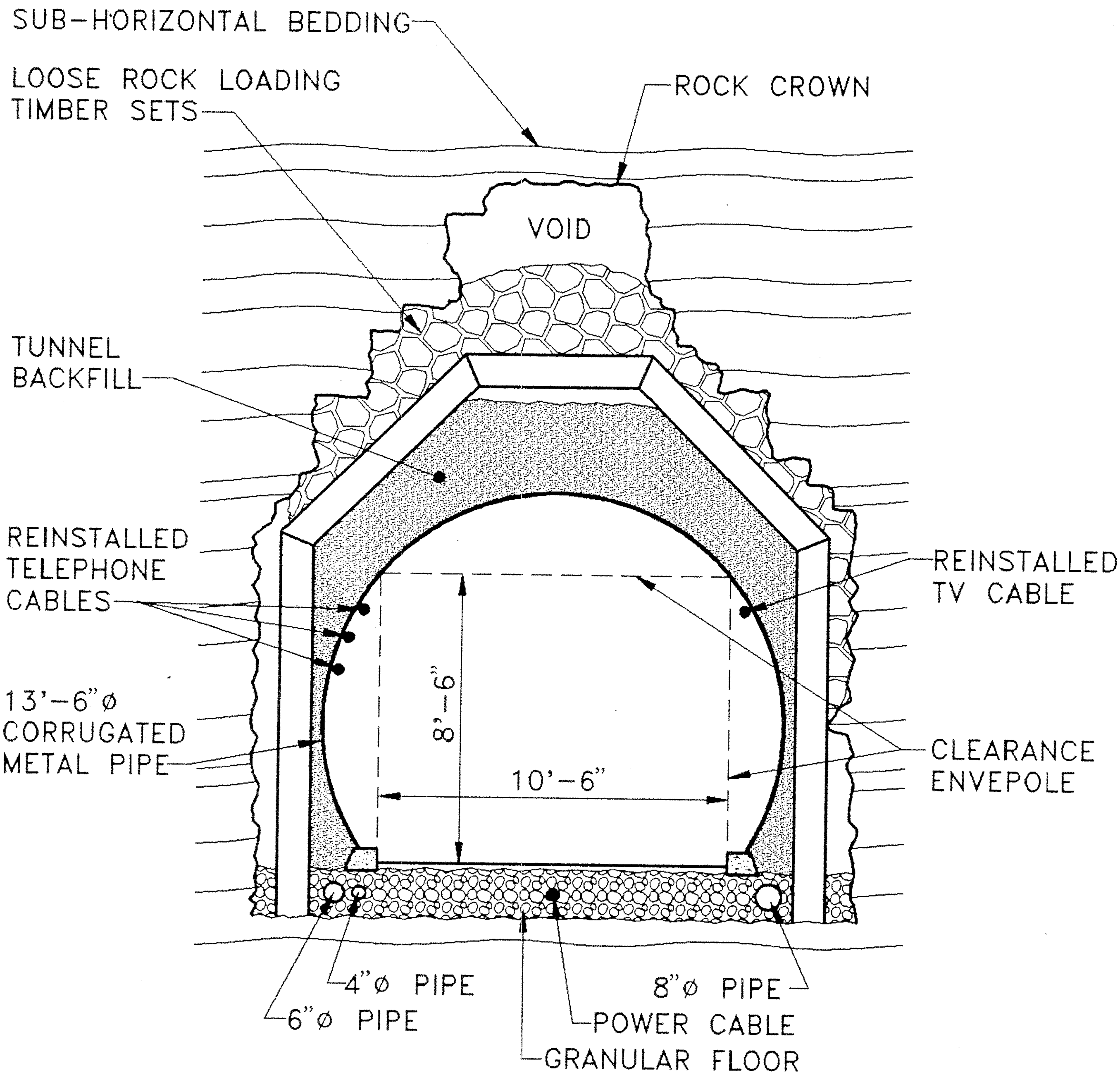
LITTLE TUNNEL - REPAIR OPTIONS

OPTIONS	Comparative Initial Cost ($)	Estimated Maintenance ($/year)	Risk	Use as Trail
1. Do nothing.	$10,000	$0/year	High	No
2. Repair collapse and remove worst timber sets and support with shotcrete and bolts.	$229,100	$30,000/year	Moderate	No
3. Install corrugated pipe and backfill void above pipe.	$351,600	$0/year	Low	Yes
4. Removal all timber sets. Install bolts and shotcrete.	$403,120	$0/year	Low	Yes
5. Construct concrete structures in bays.	$463,000	$0/year	Low to Moderate	Yes
6. Backfill tunnel.	$122,000	$0/year	Low	No



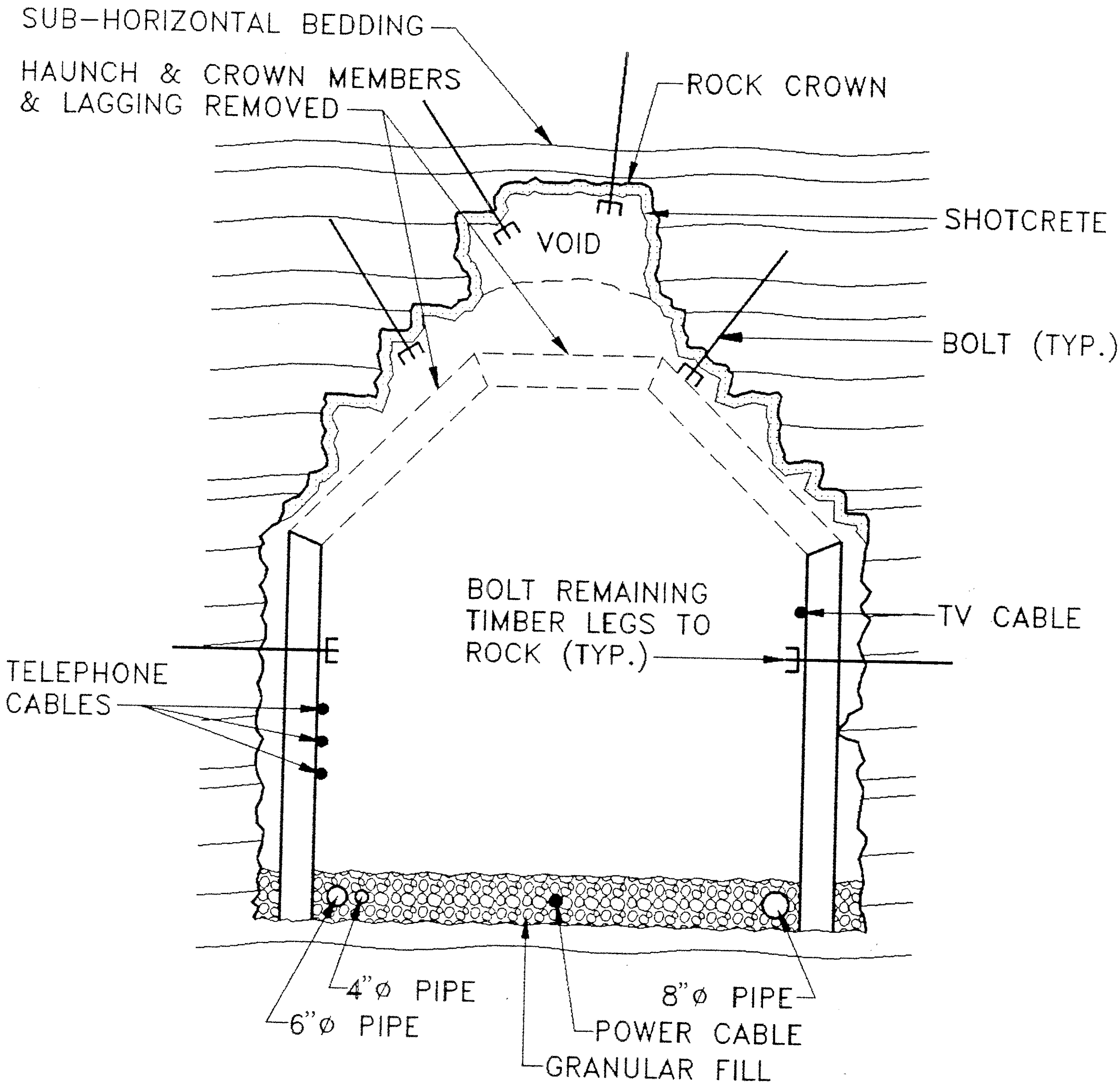
TYPICAL CONDITIONS IN TUNNEL
LINED WITH TIMBER SETS & LAGGING

Golder Associates, Atlanta, Georgia	TITLE: TYPICAL CONDITIONS IN TUNNEL LINED WITH TIMBER SETS & LAGGING				
CLIENT/PROJECT: LITTLE TUNNEL, CUMBERLAND GAP, TN FHWA/NPS	DRAWN: RMS	DATE: 2/95	JOB NO. 953-3720		
	CHECKED	SCALE: NTS	DWG NO. 1	REV. NO.	
	REVIEWED	FILE NO. 953-3720	SUBTITLE	FIGURE NO. 1	



STABILIZATION OPTION 3
INSTALL METAL HALF-PIPE

Golder Associates, Atlanta, Georgia	TITLE: STABILIZATION OPTION 3				
CLIENT/PROJECT: LITTLE TUNNEL, CUMBERLAND GAP, TN FHWA/NPS	DRAWN: RMS	DATE: 2/95	JOB NO. 953-3720		
	CHECKED	SCALE: NTS	DWG NO. 3	REV. NO.	
	REVIEWED	FILE NO. 953-3720	SUBTITLE	FIGURE NO. 3	



REMOVE TIMBER SETS & STABILIZE ROCK CROWN WITH ROCKBOLTS & SHOTCRETE

Golder Associates, Atlanta, Georgia	TITLE: STABILIZATION OPTION 4				
CLIENT/PROJECT: LITTLE TUNNEL, CUMBERLAND GAP, TN FHWA/NPS	DRAWN: RMS	DATE: 2/95	JOB NO. 953-3720		
	CHECKED:	SCALE: NTS	DWG NO. 4	REV. NO.	
	REVIEWED:	FILE NO. 953-3720	SUBTITLE	FIGURE NO. 4	

APPENDIX A

Stability Evaluation of Little Tunnel, Cumberland Gap, Tennessee.

Report by Golder Associates, May 1986.

Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

REPORT ON

STABILITY EVALUATION OF LITTLE TUNNEL
CUMBERLAND GAP, TENNESSEE

Prepared for:

Lee Wan & Associates
4321 Memorial Dr., Suite P
Decatur, GA 30032

DISTRIBUTION:

4 Copies - Lee Wan & Associates
3 Copies - Federal Highway Administration
3 Copies - Golder Associates

May 1986

853-3256

GOLDER ASSOCIATES, INC. • 3772 PLEASANTDALE ROAD, SUITE 165, ATLANTA, GEORGIA 30340, U.S.A. • TELEPHONE (404) 496-1893 • TELEX 700523

OFFICES IN UNITED STATES • CANADA • UNITED KINGDOM • AUSTRALIA

Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

May 23, 1986 853-3256

Federal Highway Administration
Cumberland Gap Project
P.O. Box 15
Harrogate, TN 37752

Attn: James R. Campbell

Enclosed please find a copy of our report on Little Tunnel. Revisions have been made to the draft report incorporating your's and Lee Wan's comments.

We appreciate the opportunity to work with you on this project and any further work in which we can be of assistance. If you have any questions, please contact us.

Very truly yours,

GOLDER ASSOCIATES

W. Randall Sullivan, P.E.
Associate

Richard W. Humphries, P.Eng.
Associate

WRS/RWH:cee

Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

May 23, 1986 853-3256

Lee Wan & Associates
4321 Memorial Dr., Suite P
Decatur, GA 30032

Attention: Mr. Michael Stieferman, P.E.

RE: RELOCATION OF U.S. 25E
CUMBERLAND GAP, TENNESSEE

Gentlemen:

Enclosed please find a copy of our revised report on Little Tunnel. Revisions have been made as per your comments and one additional solution has been included which has changed the recommendations. To avoid reproducing additional copies of the photographic record, will you please substitute these pages of the text and the title pages for those in the original draft copy that was sent you on March 7, 1986.

We appreciate the opportunity to assist you on this project and we look forward to working with you on the design of the remediation. If you have any questions, please contact us.

We are sending copies of this final report directly to FHWA as discussed previously.

Very truly yours,

GOLDER ASSOCIATES

W. Randall Sullivan, P.E.
Associate

Richard W. Humphries, P.E.
Associate

WRS/RWH:cee

Enclosure

EXECUTIVE SUMMARY

Little Tunnel is a 1000-ft. long single-track railroad tunnel built in the 1890's. The eastern 758 ft. of the tunnel is supported by a system of timber sets and lagging. The remaining 276 ft. is supported by a brick lining.

The brick-lined section is in excellent condition. It is expected to carry the additional load imposed by the planned highway embankments with a wide margin of safety.

Most of the timber and lagging have surface deterioration, but are still capable of carrying substantial loads. In a small percentage of the tunnel, the lagging has deteriorated severely or is absent entirely.

Serious stability problems exist at three locations in the tunnel. The locations of these, the nature of the problem, and the recommended remedial measures are as follows:

1. Bays 183 through 187: Timbers in the left haunch are distorted and sets severely deteriorated. The planned U.S. 58 embankment crosses the tunnel at this location. Thus, remedial work should be completed before the embankment is constructed.

   The recommended remedial work involves constructing a reinforced concrete liner immediately below the existing lagging, conforming to the shape of the existing timber set and lagging system.

2. Set 105-106: Here the crown member has displaced downward under load and is not in full contact with the right haunch member.

It is recommended that the set be repaired by bolting a new timber crown piece to the existing one and to the haunches.

3. East portal through Bay 12: Timbers in the right haunch are distorted from Bays 8 through 12 and corresponding ground subsidence can be seen at the surface above Bays 8 through 12. Ground subsidence can also be seen between Bay 8 and the portal.

   The recommended remedial work involves constructing a reinforced concrete liner, similar to Bays 183 through 187. In addition, suspected large existing voids above the tunnel crown should be filled by pumping in a sand slurry from ground surface, following completion of the reinforced concrete work. Finally the ground above the east portal section will be graded and the existing subsidence depressions filled in.

It is recommended that vibration monitoring be carried out in Little Tunnel during the nearby excavation for U.S. 25E and that the peak particle velocity be limited to 2 in. per sec.

TABLE OF CONTENTS

1.0 INTRODUCTION

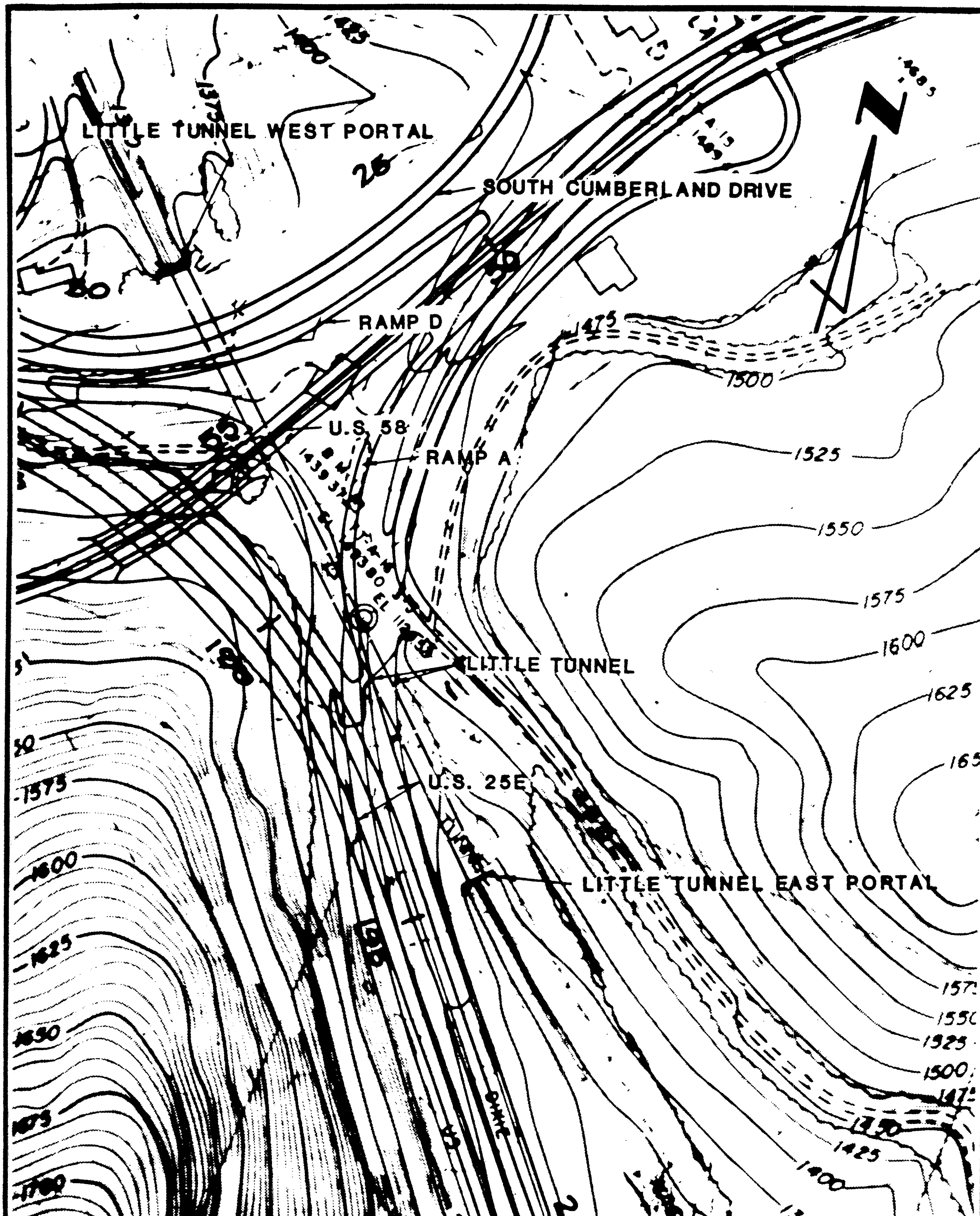
Little Tunnel is a single-track, 1000 ft. long railroad tunnel located between Cumberland Gap and Harrogate, Tennessee. It was constructed in the 1890's.

The Federal Highway Administration (FHWA) is serving as the project manager for the National Park Service on the relocation of U.S. 25E between Cumberland Gap, Tennessee and Middlesboro, Kentucky. A part of the highway relocation involves embankment construction above Little Tunnel.

A current proposal calls for possibly using Little Tunnel as a utility corridor. Under these plans, the tunnel would house water and sewer lines and a high voltage electrical transmission line.

Design work for the part of the highway relocation in Tennessee (and a very small section in Virginia) is being carried out by Lee Wan and Associates of Atlanta, Georgia. In 1984, Golder Associates, acting as sub-consultants to Lee Wan & Associates, conducted a field investigation and provided geotechnical design recommendations for surface construction on the project. The report on that work was dated June 21, 1984. It was agreed in 1984 that Golder Associates' detailed survey of conditions in Little Tunnel would be delayed until construction began on the pilot tunnel through Cumberland Mountain.

The location of Little Tunnel in reference to the highway relocation work is shown in Figure 1. The present owner of the tunnel is the Seaboard System Railroad, Inc. The line and the tunnel have been essentially abandoned for a number of years and recently Seaboard has applied to officially abandon them. We understand that, upon abandonment by the railroad, the ownership of the tunnel reverts back to



JOB NO. 853-3256	SCALE 1" — 200'	SITE PLAN – LITTLE TUNNEL	
DRAWN JLW	DATE 2-18-86		
CHECKED	DWG. NO.		
Golder Associates		LEE WAN & ASSOCIATES	FIGURE 1

the original land owners or their successors--in this case, with right-of-way acquisition for the highway relocation, the National Park Service would ultimately become the owners of Little Tunnel.

Golder Associates' scope of work on Little Tunnel is as follows:

1. Carry out a condition survey of the existing brick and timber supports,

2. Develop a photographic record of the tunnel supports,

3. Install convergence points at representative and critical locations for monitoring support behavior during highway construction,

4. Evaluate the effect of proposed highway construction on the stability of the tunnel,

5. Recommend remedial measures needed to make the tunnel suitable for use as a utility corridor.

This report provides the results of the condition survey, an evaluation of tunnel stability, and recommendations for remedial measures. The sketches given in this report are conceptual. Detailed designs and specifications for construction are to be included in the design package submitted at a later date.

2.0 CONDITION SURVEY

2.1 General

The condition survey of Little Tunnel was carried out between January 21 and January 31, 1986. A 28 ft. extension ladder was used to reach the crown and haunch. A portable generator and lights provided the necessary lighting.

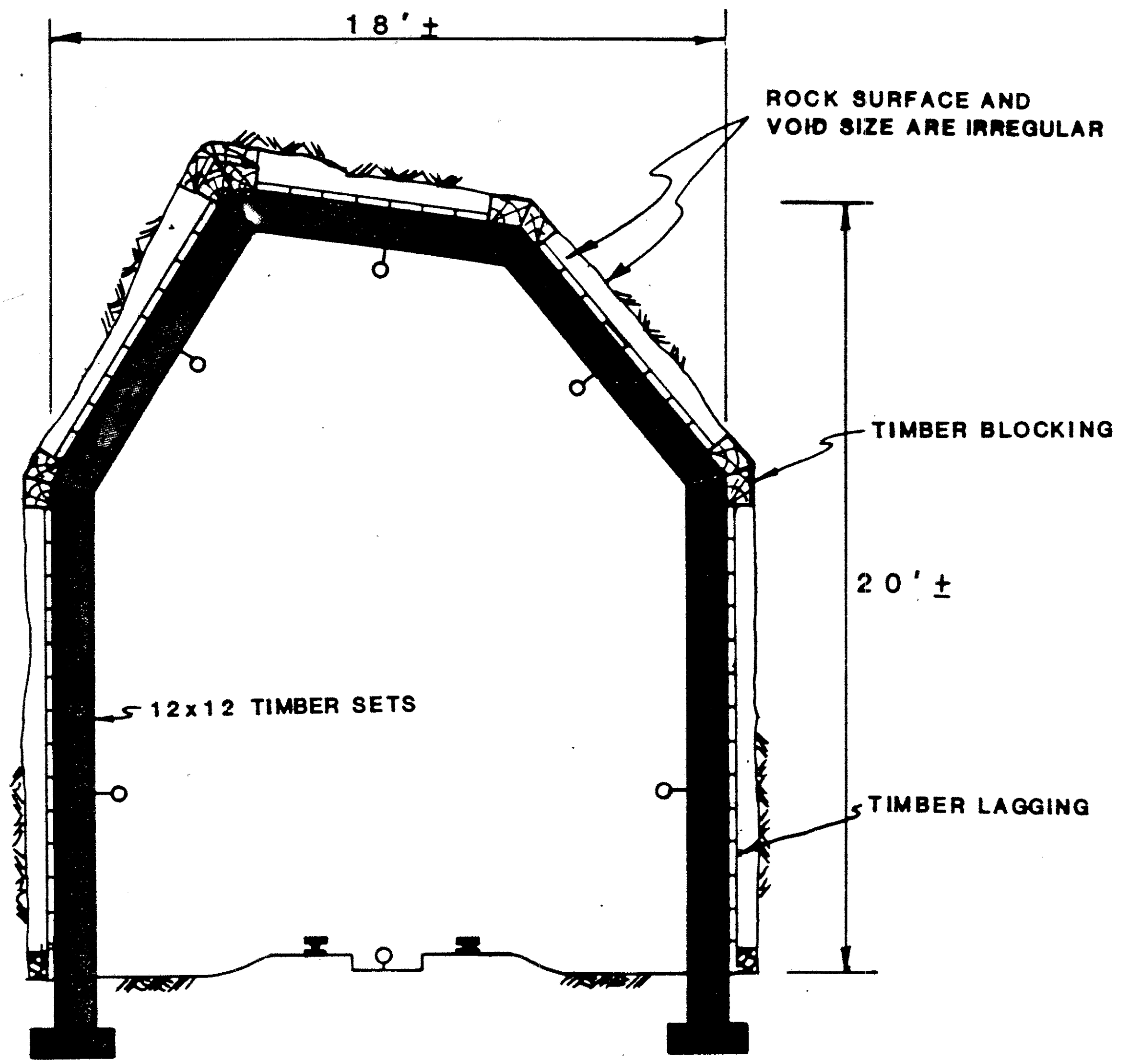
The survey began at the east portal. The outside of the first timber set was arbitrarily designated as Station 10+00. The bays between timber sets were numbered sequentially beginning with "1" at the east portal. Individual sets were identified by the bay number on each side.

The tunnel is supported by timbers from the east portal to a distance of 758 ft. from the east portal. The remaining 276 ft. is supported by a brick lining.

2.2 Timber Section

The timber support consists of 12 in. X 12 in. timber sets placed at 4 ft. on centers and 3 in. X 9 in. timber lagging. A typical cross section of a timber sets is provided in Figure 2. The practice of the day was to block the sets to the rock at the miter joints using timber cribbing. For safety reasons, we were able to actually observe the cribbing at only a few locations where it could be seen through openings in the lagging. Thus, the actual locations and conditions of the cribbing remain unknown.

The rock was observed to be tight against the lagging in some places, while voids up to 4 ft. deep were seen in other places. Typically, the void between the lagging and the rock was larger above the haunches and crown than behind the walls.



NOTE:

1. LENGTHS OF SET MEMBERS, HAUNCH AND CROWN ANGLES VARY.
2. BLOCKING TO ROCK MAY VARY FROM THAT SHOWN.

LEGEND

—o EYEBOLTS FOR CONVERGENCE MONITORING LOCATED AT STA. 17+25.6 and 17+53.6.

JOB NO. 853-3256	SCALE 1" = 5'	TYPICAL TIMBER SUPPORTED SECTION	
DRAWN SKB	DATE 2-14-86		
CHECKED	DWG. NO.		
Golder Associates		LEE WAN & ASSOCIATES	FIGURE 2

The condition of the timber sets and lagging is depicted in Figure 3. Figure 3 is a plan view of the tunnel with the haunches and sides folded up to a horizontal plane. Only conditions that appeared to deviate substantially from the typical condition are shown in Figure 3. It should be noted that the conditions shown in Figure 3 are based largely on visual observation. A physical examination was conducted at representative locations throughout the tunnel length. A detailed physical examination of each timber was beyond the scope of the investigation.

Typically, the timber sets and lagging are rotted on the surface but otherwise appear to be sound and capable of carrying near their original capacity. Localized splitting of the timber sets was frequently observed. The splits usually extend an inch or less into the sets and do not appear to appreciably affect their load carrying ability. Where an intermediate level of deterioration is shown in Figure 3, the set's load carrying capacity was judged to be reduced but is still substantial. Where severe deterioration is indicated, the timber is considered to retain a minimal load carrying capacity and additional support is required.

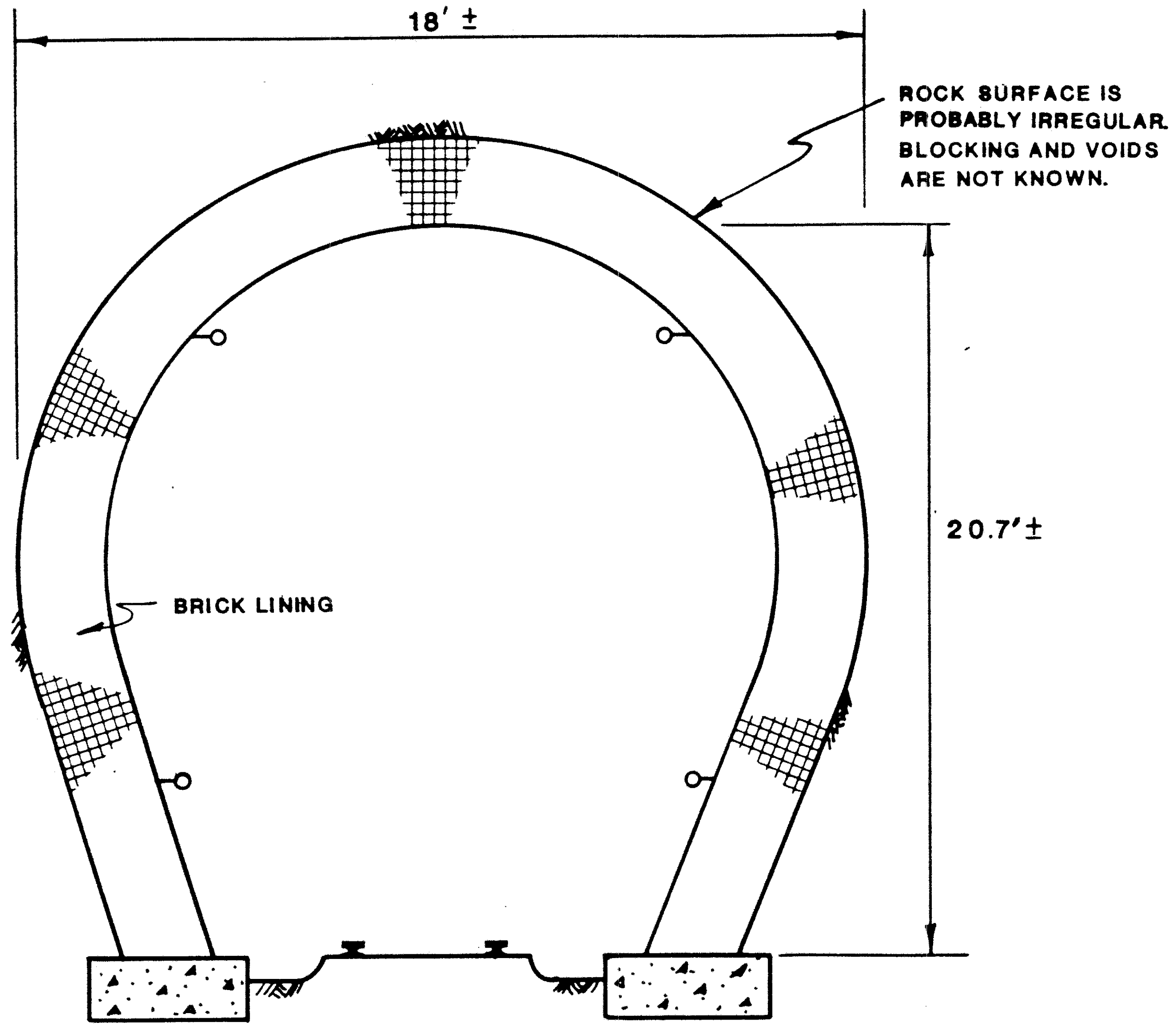
A complete photographic record of the timber supports is provided in Appendix A. Three bays are included in each set of photos. A set contains five photos: one of each wall, one of each haunch, and one in the crown. Each photo shows the number of the middle bay and an "L" and an "R" which indicate left (south) or right (north) walls respectively. The photos are arranged in Appendix A with a set of five on each sheet.

2.3 Brick Section

The brick lining is horseshoe shaped, with sides that curve inward, as shown in Figure 4. The thickness of the lining and the contact it makes with the rock can be seen only at the end of the brick lining inside the tunnel. There it has a minimum thickness of 2.1 ft. and is thicker where it was necessary to fill in irregularities in the rock. Timber cribbing is also visible in the larger irregularities. The overall width and height of the brick lining is about the same as the timber supports. This suggests that any timber sets placed during original tunnel excavation were removed as the brick lining was erected.

The brick lining is in excellent condition. Both bricks and mortar remain hard. No cracks larger than hairline in width were observed, and no active seepage was observed. There was evidence of slight seepage in the form of a light colored precipitate on the brick in some areas. The crack-free condition of the brick also suggests that the lining was built tightly against the rock. If it had not been, rock loading would almost certainly have induced moments in the brick lining at some locations and caused it to crack.

It was agreed with FHWA during the field inspection that photos covering the entire brick lining would not be necessary, given its excellent condition. Photos taken at two typical stations are provided in Appendix A. The two stations selected were those where convergence points were installed. These locations also correspond approximately to the locations where highway embankments will be built above the brick lined section.



NOTE:

1. SHAPE OF ROCK SURFACE BEHIND BRICK IS UNKNOWN.

LEGEND

—o EYEBOLTS FOR CONVERGENCE MONITORING LOCATED AT STA. 18-75 and 19-7.0.

JOB NO. 853-3256	SCALE N.T.S.	TYPICAL BRICK SUPPORTED SECTION	
DRAWN SKB	DATE 2-14-86		
CHECKED	DWG. NO.		
Golder Associates		LEE WAN & ASSOCIATES	FIGURE 4

2.4 Portals

Photos of the portals are provided at the beginning of Appendix A. The west portal headwall appears to be in satisfactory condition. There is no evidence of any surface subsidence or slope instability at the west portal.

At the east portal there are major stability problems. We observed two large subsidence pits centered at about 16 ft. and 36 ft. behind the headwall and another small subsidence immediately behind the headwall (see Figure 9). The subsidence pit at 36 ft. behind the headwall corresponds to the bulge in the timber supports within the tunnel from Bay 8 through 12.

2.5 Convergence Points

Sets of convergence points, consisting of galvanized steel eye bolts, were installed at four locations. Two sets were installed in timber sections and two sets in the brick lining. Those in the timber section are located approximately where the embankment for U.S. 58 will cross the tunnel. The two brick sections were located approximately where the Ramp D and South Cumberland Drive embankments will cross the tunnel.

The locations of convergence points on the timber and brick cross-sections are shown in Figures 2 and 4 respectively. Points were marked in the field with red spray paint. Station locations of the instrumented cross-section are as follows:

NO.	SUPPORT	STATION
1	Timber	17+25.6
2	Timber	17+53.6
3	Brick	18+75
4	Brick	19+70

An estimate of the acceptable movements in the tunnel during embankment construction can be made by estimating the elastic compression of the supports due to the embankment load. To do this, certain assumptions must be made concerning the distribution of the added load with depth and the stiffness of the supports.

Elastic theory suggests the vertical stress increase in the crown of the tunnel due to the additional load from the new embankment crossing a short section of the tunnel is about 50 percent of maximum stress applied by the embankment at the ground surface. The maximum height of the embankment crossing the tunnel is 16 ft. above existing ground level, and the corresponding increase in vertical stress at tunnel crown level due to the embankment is estimated at 1200 psf.

In the case of the timber supported section beneath the 16 ft. high U.S. 58 embankment, the rock is many times stiffer than the flexible timber support system and the additional load is expected to be carried fully by the stiffer tunnel wall rock. Thus, convergence at monitoring stations in the timber sets are expected to be less than the measuring accuracy of the tape extensometer: (0.005 in.).

In the case of the brick lined section, the stiffness of the support is much greater than with timbers. Thus, the brick lining is expected to take much of the 1200 psf of additional load. However, the stiffness of this 2 ft. thick lining is so large that the resulting elastic movement is estimated to be less than the measuring accuracy of the tape extensometer (0.005 in.).

It is anticipated that the convergence at the four instrumented locations will be less than the 0.005 in. measuring accuracy of the tape extensometer. Thus, if any measurable, systematic convergence is observed, it will probably be a result of inelastic behavior, i.e. dislodging of blocks by vibration or the re-distribution of loads around the opening. In the event of measurable movements, Golder Associates should be contacted and the cause of the movement should be investigated before additional fill is placed over the tunnel.

3.0 GEOLOGY

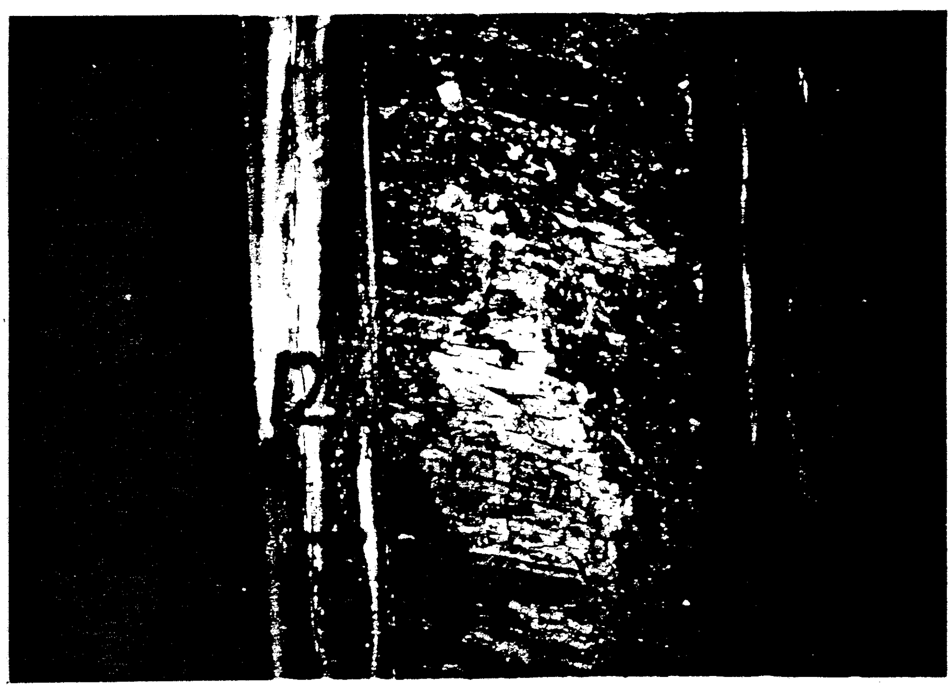
The tunnel is constructed in the Sequatchie and Rockwood Formations. These units are described in the literature as a calcareous silty shale and an interbedded sandstone and shale respectively. The contact between these formations occurs in the brick lined section of the tunnel and thus was not observed.

Exposed rock (Sequatchie Formation) in the tunnel sidewalls is primarily limestone with occasional calcareous shale interbeds. Photos of typical rock exposure are shown in Figure 5. The limestone is grey, hard, fine grained, and unweathered. Joints are infrequent and no weathering was observed. Bedding dips measured in the tunnel range from 17^{o} to 20^{o} and dip directions range from 312^{o} to 315^{o}. The dip direction is approximately parallel to the tunnel alignment. Water inflows are generally small (<5 gpm) and in some areas have resulted in a precipitate forming (presumably $CaCO_3$) on some rock surfaces and tunnel support. The interbedded shale is primarily dark red in color and is locally calcareous. The shale weathers on exposure and small/minor rockfalls have occurred as a result.

Thicknesses of the beds in the limestone range from 1/2 in. up to several feet. Typically beds are about 8 in. thick and can be traced for ten's of feet. A Rock Mass Rating (Reference 1) of 50 was estimated for the limestone exposed in the tunnel.

Rock exposed in slopes at the east portal (Sequatchie Fm) is moderately to highly weathered calcareous shale with shale interbeds. Localized sloughing has occurred due to weathering. Slope angles range from 80^{o} to 85^{o} for the rock cuts and from 30^{o} to 45^{o} for the more weathered rock/soil slopes.

Figure 5
Typical rock exposed
in tunnel



The slopes at the west portal are composed of interbedded sandstone and shale of the Rockwood Formation. Weathering of the shales has resulted in minor sloughing of the near vertical slopes.

Slope stability at the portals is not expected to be significantly influenced by rock structure. Existing and proposed cut slopes are oriented such that the adverse condition, where bedding dips into the excavation, does not occur.

Generally, two failure modes must be considered in the evaluation of underground openings in rock. One involves sliding or fall out of rock blocks bounded by existing structural features, such as bedding and joints. The other involves stress failures in intact rock. With the shallow overburden and high strength rock at Little Tunnel, stress failures can be eliminated from further consideration. Consideration needs to be given only to support loads arising due to the movement of rock blocks bounded by existing structural features.

4.0 EVALUATION OF TUNNEL STABILITY

4.1 Existing Conditions

The existing conditions in the tunnel can be grouped as follows:

1. Sections where the supports are overloaded and have distorted as a result;
2. Sections where the supports have proved adequate to carry the imposed rock loads;
3. Sections where the rock is self-supporting and the condition of the supports is not important for tunnel stability.

The first condition exists at three locations in the tunnel. At Bays 8 through 12 the sets and lagging are bulged inward in the right haunch (Figure 6a). At Set 105-106 the right haunch member has been pushed inward and barely remains in contact with the crown member (Figure 6b). At Bays 183 through 187 the sets and lagging are bulged inward at the left haunch (Figure 7a).

Bulging has also occurred at Bays 181 and 182 (Figure 7b). It appears that high loads distorted and damaged the original timber sets and that additional sets were placed to take the load. The additional sets are undamaged and are providing the required support. Bays 181 and 182 are examples of the second condition.

Sets 18-19 and 23-24 are examples of the third condition where the rock is self-supporting. The right legs of these sets are so severely deteriorated that if any appreciable rock load existed, collapse would have already occurred.

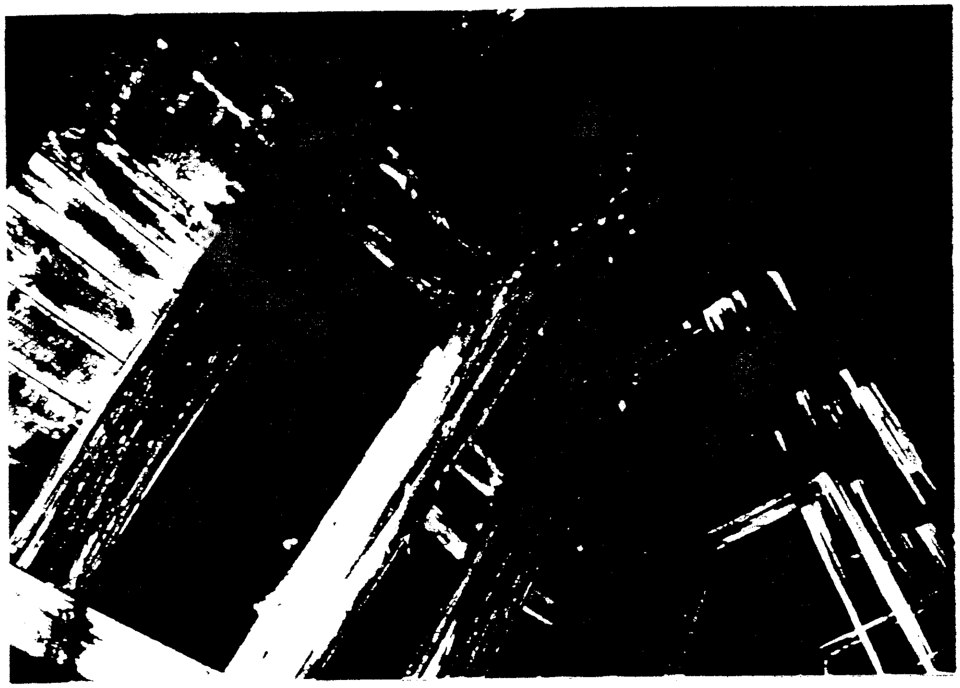


Figure 6a
Distortion of
right haunch at
Bays 8 through, 12

Figure 6b
Distortion of
right haunch at
Set 105-106

Figure 7a
Distortion of
left haunch at
Bays 183 through 186

Figure 7b
Distortion of
right haunch at
Bays 181 and 182

More than 80 years of adequate performance indicates that the remaining sections of the tunnel fall into one of the latter two categories. That is, they either have supports adequate to carry the imposed loads, or the rock is self-supporting. The good quality of the rock mass where exposed in the timber section, also suggests that the rock is self-supporting over much of the tunnel. However, some gradual loosening and spalling may have taken place in localized areas of poorer quality rock. Such rock would be more suspectible to freeze-thaw action, joint weathering mechanisms, and stress-redistribution phenomena, over the long term.

4.2 Effect of Highway Construction

Highway relocation work around Little Tunnel will involve the construction of embankments up to about 16 ft. high over the tunnel centerline. Blasting for cuts on U.S. 25E will be done within about 40 ft. horizontally from tunnel centerline and at an elevation about 60 ft. above the tunnel crown. The location of Little Tunnel in relation to the highway construction is shown in Figure 1.

Embankments for South Cumberland Drive and Ramp D will be 11 ft. and 16 ft. high respectively and will be built over the brick lined section of the tunnel. These embankments are expected to have a minimal effect on the brick lining. As discussed previously, our observations and the excellent performance of the brick section suggest that it was built reasonably tight against the rock. This means that the interaction of the ground and the liner will prevent appreciable moments from developing and any additional load exerted by the embankments will be carried almost totally in thrust. The brick lining is estimated to have sufficient thrust capacity to support more than 150 ft. of overburden. Thus, the addition of 16 ft. of fill, which brings the total overburden thickness to about 75 ft., is expected to be carried by the brick lining with a wide margin of safety.

The embankment where U.S. 58 will cross the tunnel is about 16 ft. high and passes over one of the problem areas in the timber supported section. Additional support will be required in the problem area between Bays 183 and 187 before construction of the U.S. 58 embankment. Recommendations for the remedial work are provided in Section 5 of this report.

Ramp A will also pass over the timber section of tunnel at about tunnel Station 14+00. At that location, Ramp A is approximately at existing grade and thus no appreciable change in load should occur in the tunnel supports.

For control of blasting during excavations for U.S. 25E near Little Tunnel, we recommend measuring peak particle velocities during blasting and limiting these to 2 in. per sec at the tunnel crown.

Two in. per sec. is the safe blasting criteria recommended by the U.S. Bureau of Miners for residential structures. It is recommended in this application because the vibration level that will cause damage in the brick tunnel lining is expected to be approximately the same as in a residential structure.

Measurements should be made in the rock at about Bay 184 and in the brick lining near its eastern end. Peak particle velocity for a blast at a given distance from a sensitive structure can be controlled by limiting the charge weight detonated per delay. Approximate charge weights per delay to limit peak particle velocity to 2 in. per sec. are estimated as follows (Reference 2):

Distance (ft.)	Charge Wt. per Delay (lb.)
50	8
75	25
100	60
200	450

These should be used only to guide bidders, as measured attenuation of vibration could change the allowable charge weights substantially.

As an added precaution, we recommend that measures be taken to prevent anyone, other than project personnel from entering the tunnel during the highway construction period.

4.3 Stability During Utility Installation

It is recommended that this report be provided to contractors bidding on the utility work so that they are fully aware of conditions throughout the tunnel before undertaking the work. Utility contractors should be aware that if their operations disturb the existing supports, there is the danger of rock falls from the crown and haunch.

If the project schedule will permit, the remedial measures recommended below should be completed before utilities are installed through the tunnel. Failure is not believed to be imminent at the three problem sections, but, depending on the nature of the utility construction, temporary supports may be required in these areas if the utility work is done before the permanent remedial work.

If remedial measures are completed before utility installation, and the utility contractor is careful not to disturb the tunnel supports, the tunnel is not expected to present any unusual hazard to utility installation.

4.4 Long-Term Stability

The three locations described in Section 4.1 with overloaded supports present the greatest threats to long-term stability. Remedial work at Bays 183 through 187 is required before construction of the U.S. 58 embankment. If the tunnel is to be used as a utility corridor, or if the Park Service becomes the owner, remedial work is also recommended at Set 105-106 and at the east portal. Recommended remedial measures are provided in the next section.

For the remainder of the tunnel, some further deterioration of the timber supports should be expected. Minor rockfalls may occur where no lagging is present. As the sets and the timber cribbing between the sets and the rock deteriorate, some additional sets may become distorted. Additional support may be required in such areas from time to time.

Considering the quality of the rock and the generally good performance of the timbers over more than 80 years in this environment, future remedial work is not expected to be a major problem. In particular, it is considered that a significant reduction in air circulation in the tunnel (through bulkheads and/or access control doors installed at the portals) would have a beneficial effect on its future stability, from the stand point of freeze-thaw action on the rock. Periodic inspection (annually or bi-annually) and maintenance of the tunnel supports is recommended. On this basis, the probability of a major collapse that might result in surface subsidence is considered very small.

5.0 RECOMMENDED REMEDIAL MEASURES

5.1 General

Remedial measures are recommended for three sections of the tunnel. These are as follows:

1. East portal through Bay 12
2. Set 105-106
3. Bays 183 through 187 near the west end of the timber-supported section.

Remedial work at the east portal will be more extensive than elsewhere. Therefore, the east portal will be considered first. Three options have been considered for stabilizing the east portal. The first option involves installation of steel sets. The second option involves installation of a reinforced concrete liner. The third option involves open cut excavation at the east end of the tunnel, thereby, shortening the tunnel and eliminating the problem section.

5.2 Steel-Set Supports (Option 1) for Stabilizing East Portal

Two criteria need to be satisfied in designing tunnel stabilization measures at the east portal. First, the large displacements that have occurred suggest that the ground has little or no arching capability remaining and that supports must be designed to carry the full overburden load. Second, the design must prevent ravelling of the type that probably led to the current surface subsidences.

The maximum overburden height in the problem area at the east portal is 25 ft. Medium weight steel sets blocked tightly to the rock will support 25 ft. of overburden. However, with this design, the potential for ravelling and surface subsidence would remain.

Ravelling can be prevented and the full overburden load supported with a design that employs steel sets to support the load and pumped-in concrete to fill the void space. The concrete serves the additional purpose of blocking the supports to the rock. The construction sequence envisioned for this option at Bays 1 through 12 is as follows:

1. Replace the severely deteriorated lagging.

2. Erect the steel sets midway between the existing timber sets and block them tightly against the lagging. The steel should be blocked at the crown and springline and elsewhere at a spacing not to exceed 42 in.

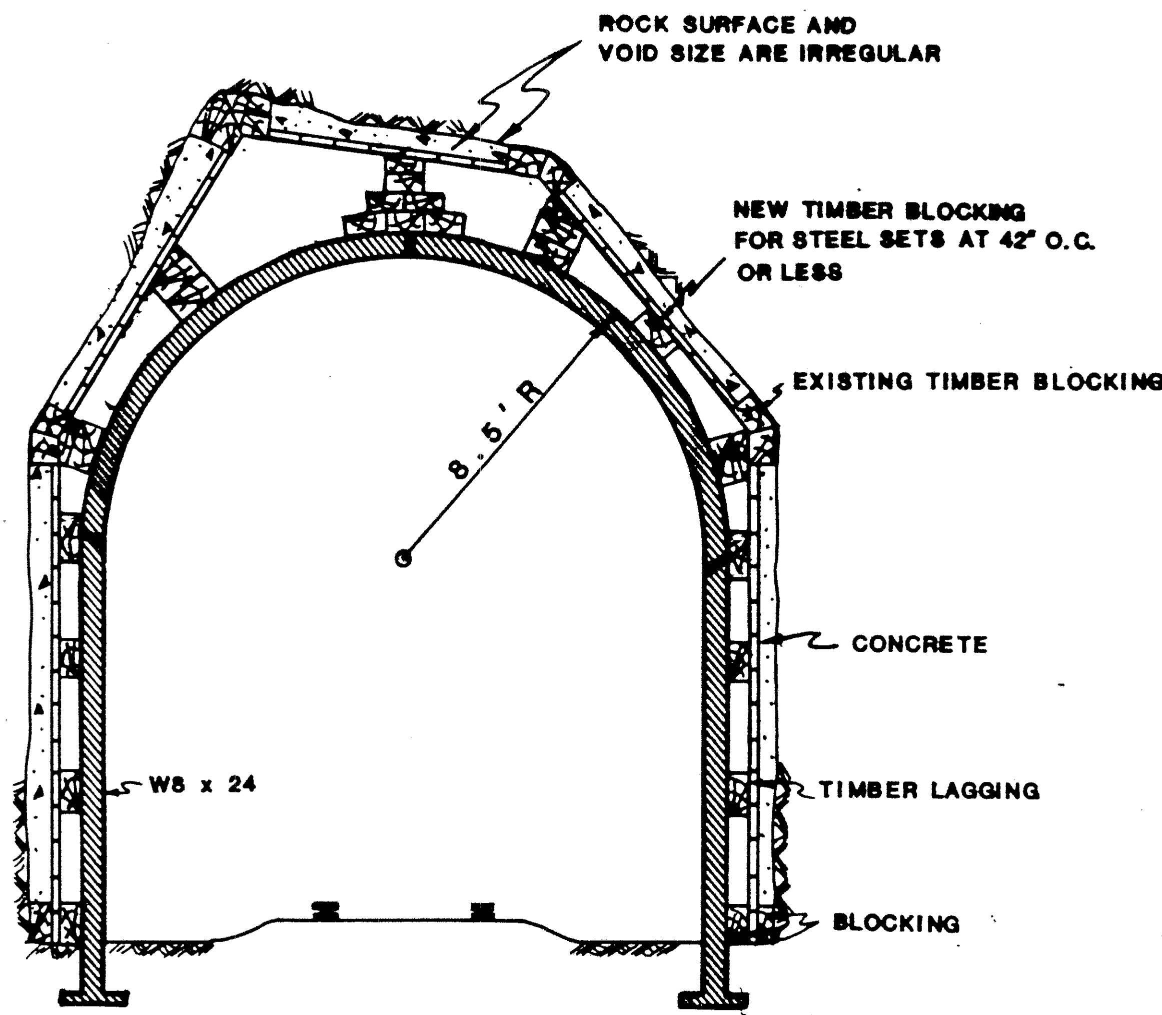
3. Construct bulkheads, as required, and pump concrete to fill the void to the maximum level possible. This typically leaves about a one foot high void in the crown.

4. Drill through the lagging and concrete, and pump grout to fill the remaining void.

5. Shotcrete over the steel sets and timber blocking to provide corrosion protection. A minimum covering of 2 in. is recommended.

6. Backfill and re-grade the subsidence pits at the surface.

Size W8 X 24 steel sets are recommended. The recommended configuration is shown in Figure 8. This size set, spaced at 4 ft. on centers, will support the full 25 ft. of overburden without any reliance on the existing timbers. The span outside-to-outside of the existing timber sets is consistently about 18 ft. However, the geometry of the haunch and crown varies considerably. The length of the timber



JOB NO. 853-3256	SCALE 1" - 5'	TYPICAL STEEL SUPPORTED SECTION AT EAST PORTAL
DRAWN SKB	DATE 2-14-86	
CHECKED	DWG. NO.	
Golder Associates		LEE WAN & ASSOCIATES — FIGURE 8

legs (on the outside) from the foot block up to the haunch was measured at several locations to be about 14.5 ft., but this dimension is also expected to vary somewhat.

5.3 Reinforced Concrete Liner (Option 2) for Stabilizing East Portal

An additional option for stabilizing the East Portal, is the construction of a reinforced concrete liner immediately below the existing timber set system. The conceptual design for this solution is shown in Figure 9.

This concept relies on casting a concrete liner tight against the existing timber lagging, in the manner shown on the figure, such that the internal support profile is essentially maintained.

The reinforcement design allows for support of the full 25 feet of overburden,, as is the case of the steel sets; without any reliance on the existing timber sets. A nominal footing, as illustrated in the figure, should be provided on the rock surface which is expected to be generally at 1 to 1.5 foot depth below existing ground surface, along the sidewalls of the tunnel.

As far as the prevention of further ravelling and subsidence above the tunnel crown with this concept, it is recommended that following construction of the concrete liner, probing be carried out from above to try to detect any remaining large voids. Filling of voids with a vertical dimension of greater than 2 feet, should then be carried out, from ground surface, by pumping a sand slurry through appropriate holes for that purpose. Finally, when the major underground voids have been substantially filled, grading and filling of the ground surface should be carried out.

5.4 Open Cut (Option 3) for Stabilizing East Portal

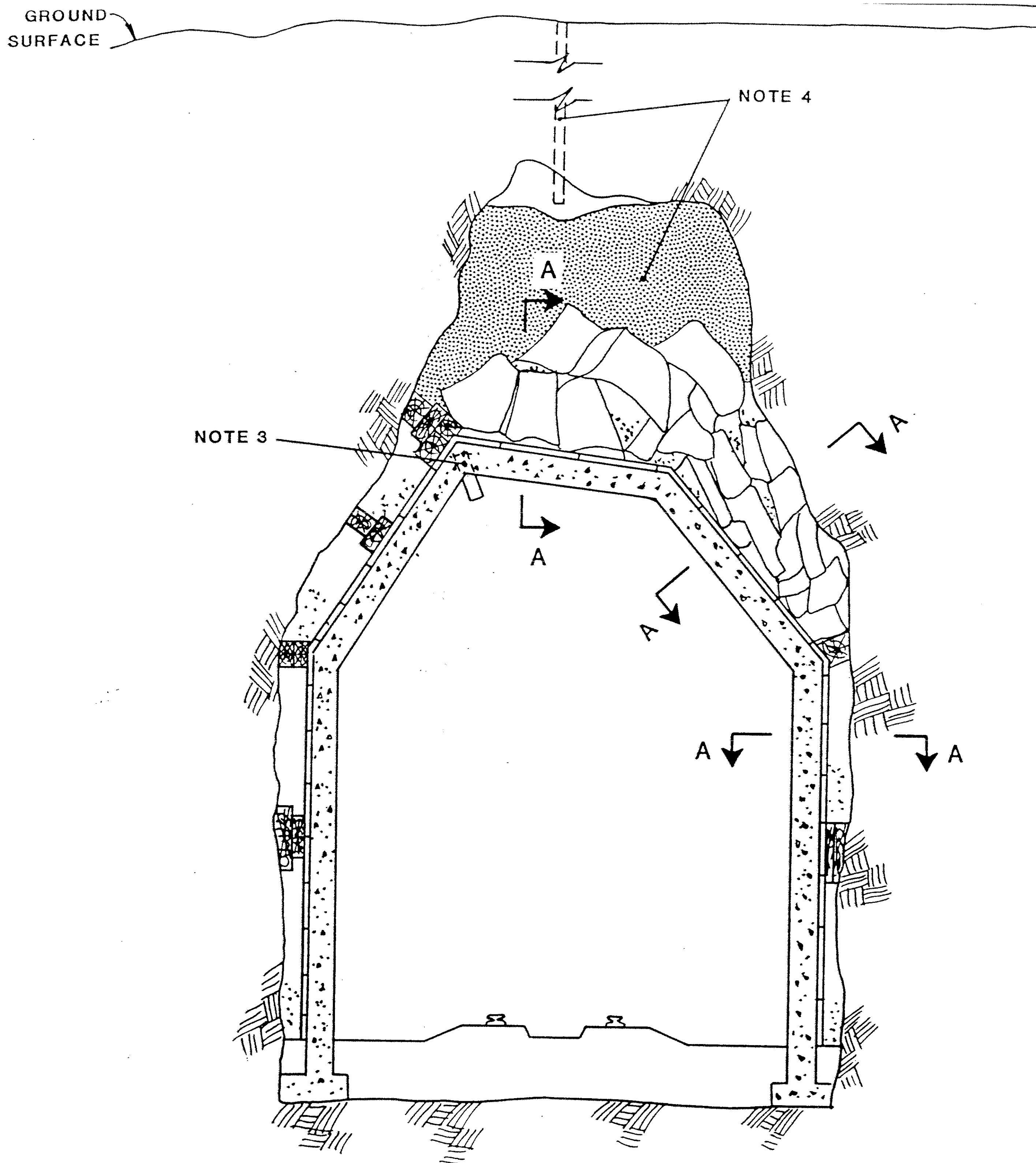
A conceptual design is shown in Figure 10 that involves making an open cut and moving the east portal back 50 ft. With this option, the problem section of the tunnel near the east portal would be eliminated. A conceptual layout of the open cut option has been prepared so that a cost comparison can be made between it and the tunnel stabilization option presented above.

The layout is based on assumed subsurface conditions and if this option is selected, an investigation of subsurface conditions will be required before final design. A soil depth of about 6 ft. and a depth to unweathered rock of about 20 ft. have been assumed. Additionally, it was necessary to estimate topography in the vicinity of the existing wall along U.S. 25E beside the portal. Apparently this wall was constructed after the project topographic mapping was done.

The conceptual design relies on steep, reinforced slopes in unweathered and weathered rock. Rockbolting on about a 5 ft. X 5 ft. pattern and mesh reinforced shotcrete are expected to be required in weathered rock. Spot bolting without shotcrete may be adequate in the fresh rock in the lower part of the cut slopes.

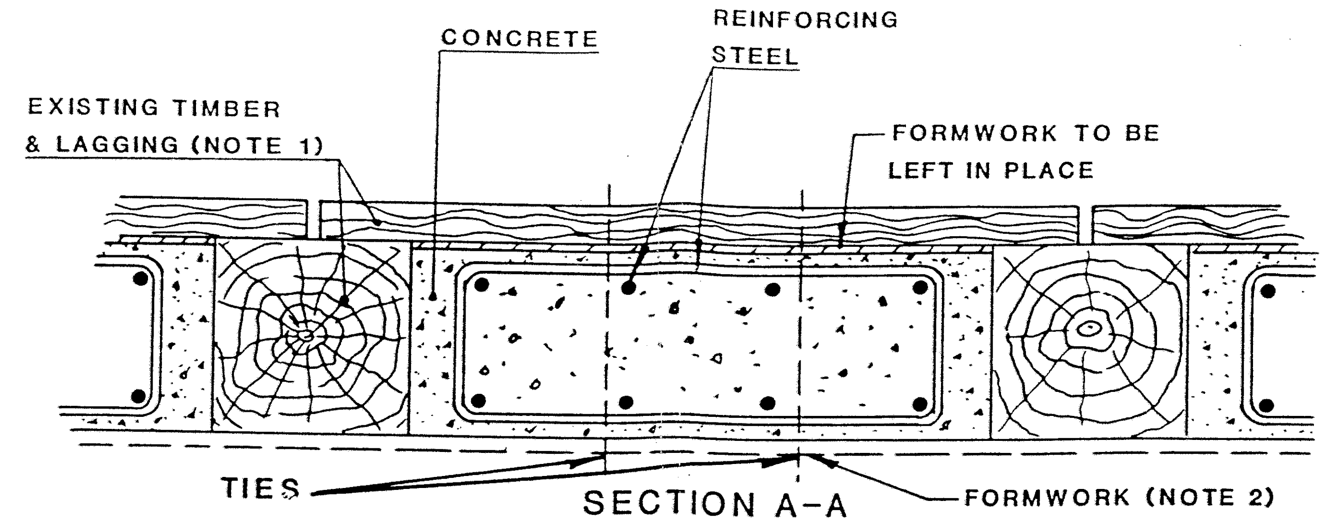
On the north side of the excavation the overburden can be laid back at a slope of 2.0 hor.:1.0 ver. On the west side, the rising topography suggests a retaining wall or soil nailing wall would be desirable in the overburden.

On the south side, the excavation encroaches on the existing retaining wall along U.S. 25E. The cross section in Figure 9 shows the constraint presented by the existing wall. The temporary excavation required to build a conven-



TYPICAL SECTION
(NOTE 5)

SCALE 1"- 5'



SECTION A-A
BAYS 1 TO 12 AND 183 TO 187

SCALE 1"- 1'

NOTES

1. EXISTING TIMBER SETS AND LAGGING TO BE LEFT IN PLACE. WHERE LAGGING IS MISSING OR WEAK IT SHOULD BE REPLACED OR EQUIVALENT MEANS SHOULD BE PROVIDED OF FORMING THE BACK FACE OF THE CONCRETE.

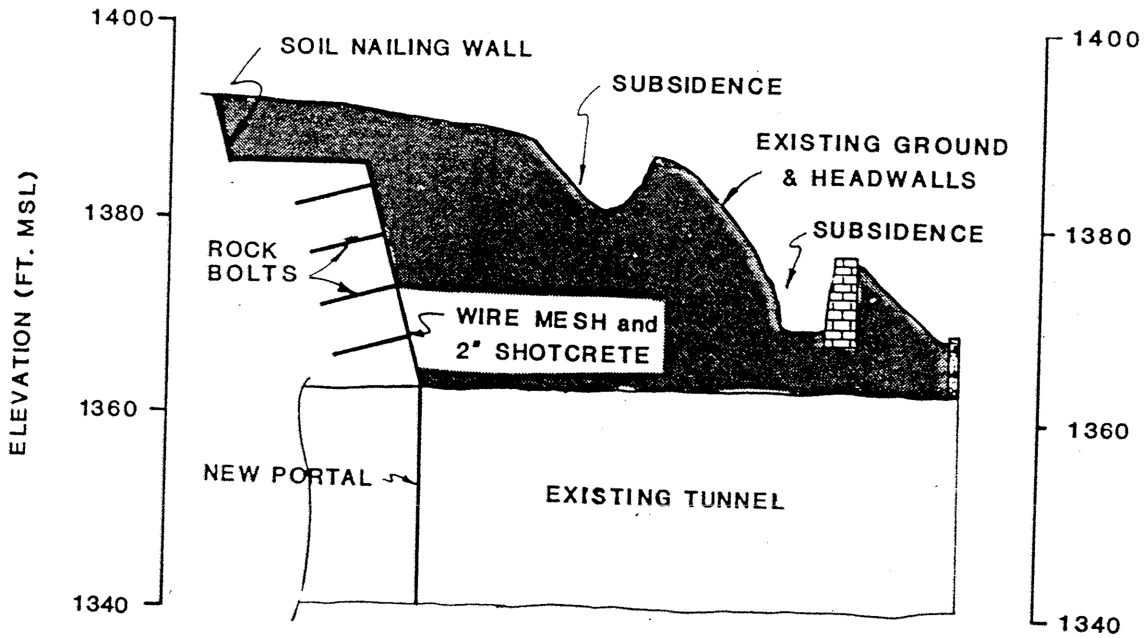
2. IN THE SIDE WALL SECTIONS THE FORMWORK SHOULD CONSIST OF APPROVED PLYWOOD AND TIED, AS SHOWN TO THE EXISTING LAGGING. IN ADDITION, IN THE HAUNCHES AND CROWN AREAS, THE FORMWORK SHOULD BE SUPPORTED BY APPROVED FALSEWORK, PRIOR TO CONCRETING. THE SIDEWALL TIE HOLES SHOULD BE LEFT OPEN, TO ACT AS WEEPHOLES.

3. CONCRETING OF THE HAUNCHES AND CROWN AREAS SHOULD BE DONE BY PUMPING INTO THE HIGHEST POINT IN EACH BAY. THE PUMPED CONCRETE SHOULD CONTAIN A SUPER PLASTICIZER ADDITIVE, TO IMPROVE ITS FLOW CHARACTERISTICS, AND THE VOLUME TO BE PUMPED SHOULD BE CAREFULLY MONITORED TO ENSURE COMPLETE FILLING OF THE CROWN SECTION.

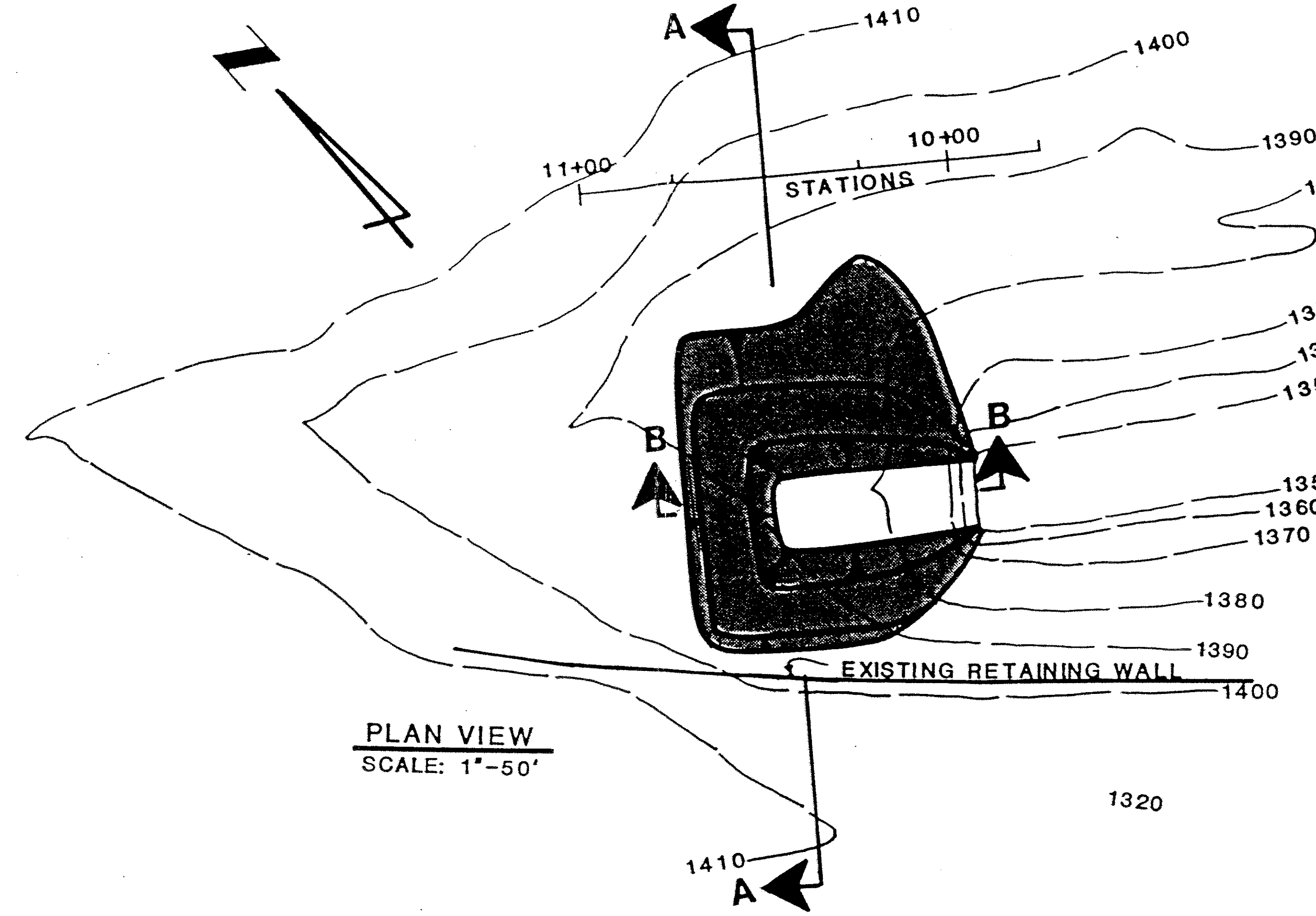
4. THE GROUND ABOVE THE EAST PORTAL AREA (BAYS 1 TO 12) SHOULD BE PROBED FROM SURFACE, AT 5' INTERVALS ALONG THE TUNNEL AXIS, FOLLOWING COMPLETION OF THE INTERNAL REINFORCED CONCRETE WORK. VOIDS LARGER THAN 2 FT. (VERTICALLY) SHOULD SUBSTANTIALLY BE FILLED BY PUMPING A SAND SLURRY FROM GROUND SURFACE, AS SHOWN.

5. THE VOID PROBING AND FILLING TREATMENT ILLUSTRATED IN THE TYPICAL SECTION, AND DESCRIBED IN NOTE 4, WILL NOT BE REQUIRED AT BAYS 183 TO 187.

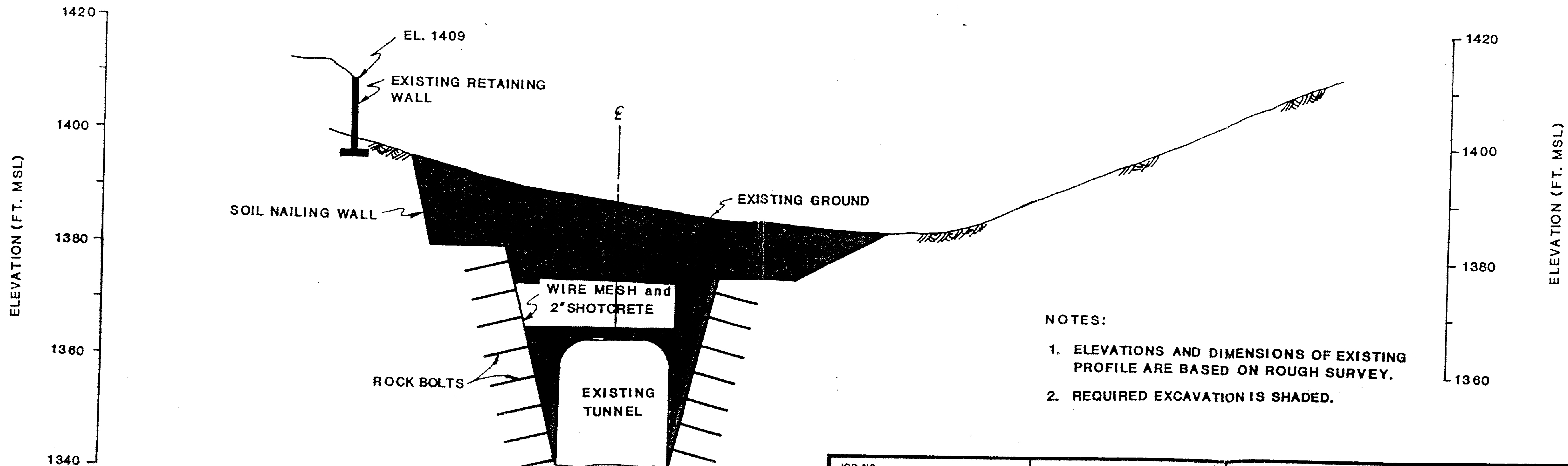
JOB NO. 853-3256	SCALE AS SHOWN	TYPICAL REINFORCED CONCRETE SUPPORT SYSTEM
DRAWN T.s.R.	DATE 5/20/86	
CHECKED	DWG. NO.	
Golder Associates		LEE WAN AND ASSOCIATES — FIGURE 9



SECTION B-B at East Portal of Little Tunnel
SCALE: 1"-20'



PLAN VIEW
SCALE: 1"-50'



SECTION A-A at Station 10+50
SCALE: 1"-20'

NOTES:

1. ELEVATIONS AND DIMENSIONS OF EXISTING PROFILE ARE BASED ON ROUGH SURVEY.
2. REQUIRED EXCAVATION IS SHADED.

JOB NO. 853-3256	SCALE AS SHOWN	CONCEPTUAL DESIGN FOR OPEN CUT OPTION AT EAST PORTAL
DRAWN SKB	DATE 2-14-86	
CHECKED	DWG. NO.	
Golder Associates		LEE WAN & ASSOCIATES — FIGURE 10

tional retaining wall founded at the estimated top of rock would threaten the stability of the existing wall. This constraint means that the open cut option is technically feasible only if a special technique, such as a tie-back wall or soil nailing wall, is used to support the overburden on the south side of the cut. The feasibility of tie-backs or soil nailing depend on subsurface conditions and on the foundation details of the existing wall.

Carefully controlled blasting will be required in making the excavation. Pre-reinforcement of the rock in the tunnel crown near the new portal is also advisable. This could be done with grouted, vertical dowels installed before blasting from the bench in the overburden above the new portal.

5.5 Remedial Measures at Set 105-106

A photo of the distorted right haunch at Set 105-106 is shown in Figure 6b. No other distortion is evident in the vicinity. Other than the poor contact between the haunch and crown member the set is in good condition.

It is recommended that another 12 in. X 12 in. crown member be bolted onto the present one and that it be mitered to fit tightly against both haunches. This repair is expected improve the capacity of the set to near its original level.

5.6 Remedial Measures at Bays 183 through 187

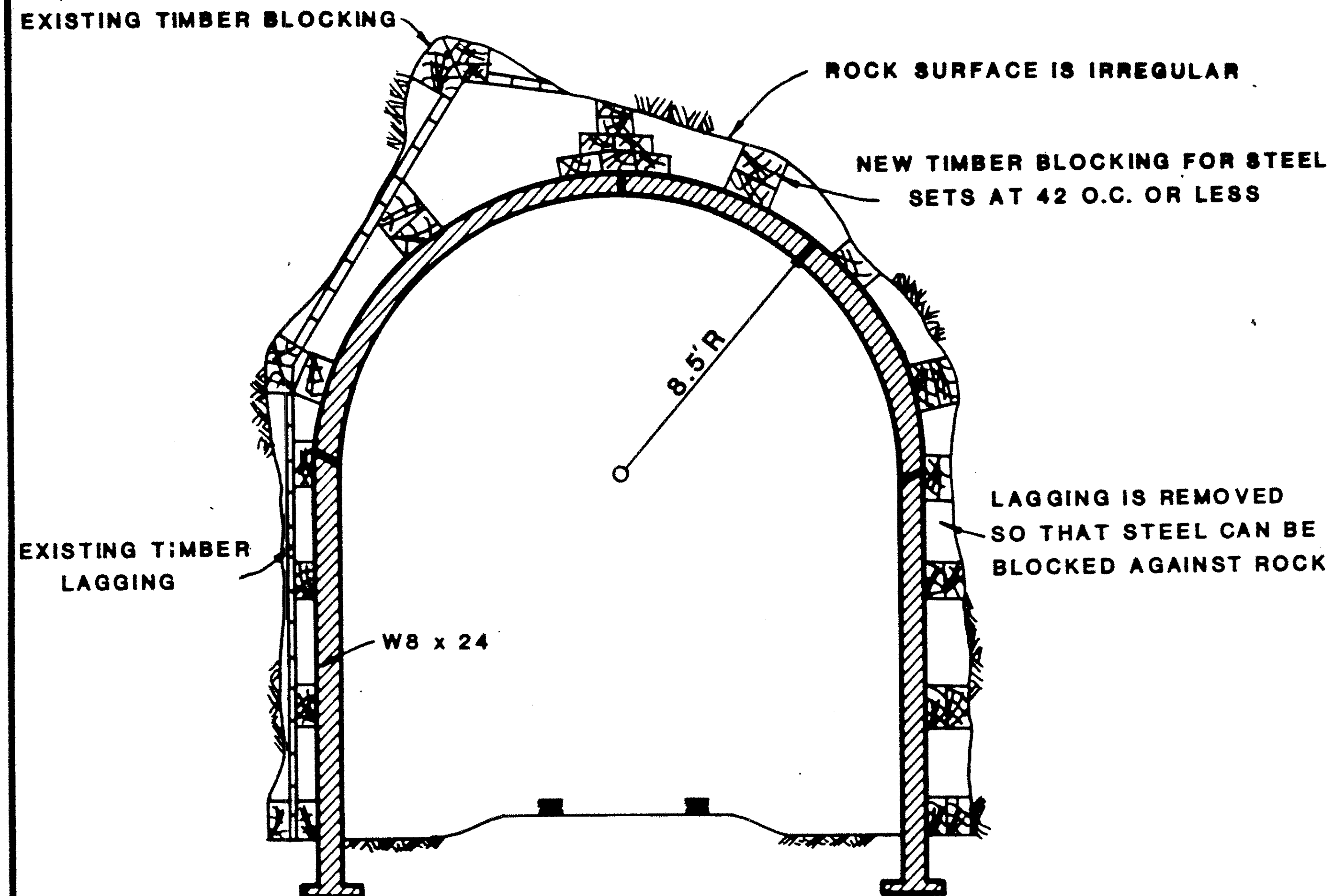
A photo of the distortion at Bays 183 through 187 is shown in Figure 7a. In addition to the distortion, the left haunch members in these bays are severely deteriorated. Thus, either steel sets or reinforced concrete are necessary to stabilize this section of the tunnel. The choice will depend on cost considerations, which are discussed in the following section of the report.

The reinforced concrete option would be the same in all respects, as already described for the East Portal and as illustrated on Figure 9, except for the probing and filling of crown void spaces. It is considered that in this case, in view of the much greater cover, there will be no need to fill existing voids to prevent ground subsidence.

For the steel sets support option, the sets would be of the same size as those recommended for the east portal work. The steel sets should be placed midway between the existing timber sets in Bays 183 through 187. They should be blocked tightly against the existing lagging in the left haunch and left portion of the crown, where the rock is clearly in contact with the lagging. Elsewhere, enough lagging should be removed so that access can be gained to block the steel tightly to the rock (see Figure 11). The steel should be blocked at the crown and springline and elsewhere at spacings not greater than 42 in. The steel sets, timber blocking, and any exposed rock should then be covered with a minimum of 2 in. of shotcrete.

5.7 Cost Estimate

Quantity and cost estimates are provided in Tables 1, 2, and 3 for the three options at the east portal, plus the repairs recommended at Set 105-106 and Bays 183 through 187. Unit prices used in the estimates were based primarily on unit prices from the pilot tunnel (E3/E6) bidding and input from FHWA senior staff at Cumberland Gap. On a project such as this where quantities are small, the estimated unit prices should be considered to have an accuracy not greater than 50 percent.



JOB NO. 853-3256	SCALE 1"-5'	TYPICAL STEEL SUPPORTED SECTION AT BAYS 183 - 187
DRAWN JLW	DATE 4/9/86	
CHECKED WDM	DWG. NO.	
Golder Associates		LEE WAN & ASSOCIATES — FIGURE 11

For the "Option 1" tunnel stabilization work, the weight of steel shown is based on using 17 steel sets, each weighing 1300 lb. Shotcrete quantities are based on an assumption that 2 cubic yards will be required to cover one set and its blocking. The concrete-grout quantity was arrived at by assuming a 2 ft. average thickness will be required around the entire perimeter. Locally, our observations indicate this thickness will vary from near zero to 4 ft. or more. Two feet is considered a reasonable average thickness but it should be remembered that there is insufficient data to actually estimate the average thickness. If an reasonable upper limit on the concrete-grout quantity is desired, we recommend using a 3 ft. average thickness.

For the "Option 2" stabilization work, the volume of concrete is based on a 1 foot thick arch of the same configuration as the existing timber sets. The void space to be filled, above the crown of the East Portal Section, was assumed to be an average of 4 feet high and 10 feet wide, over a distance of about 50 feet. The quantity of sand required to significantly fill this void was estimated at 2/3 of this volume.

For the "Option 3" (open cut) stabilization work, the excavation volume was estimated using the 1 in. = 50 ft. mapping, with a 10 ft. contour interval. Thus, for an excavation of this size the quantities should be considered fairly crude. It was assumed that the entire excavation surface below the over-burden bench will be covered with mesh reinforced shotcrete and that 8 ft. rock bolts will be installed at 5 ft. on centers. A permanent soil nailing wall was assumed to extend along the overburden cut slope on the south and west sides of the excavation. It was assumed that 20 ft. long vertical dowels will be installed at 5 ft. on centers over a 15 ft. by 20 ft. area above the new portal.

5.8 Recommendations

Our cost estimates suggest that Option 2, i.e. stabilization with a reinforced concrete liner, is significantly lower in overall cost than the other two options considered, and it is therefore our recommended solution. In addition to the lower cost, this solution involves the least specialized construction work, which is an added advantage in terms of letting contracts for the work.

The recommended repairs do not permanently eliminate all potential problems in the tunnel as some further deterioration of the timbers should be expected. The repairs discussed in this report have been recommended as a cost effective means of stabilizing the tunnel for installing the services. Regular inspections of the tunnel will be required in the future.

Very truly yours,

GOLDER ASSOCIATES

W. Randall Sullivan, P.E.
Associate

Richard W. Humphries, P.Eng.
Associate

WRS/RWH:cee

REFERENCES

1. Hoek, E. and E. T. Brown, Underground Excavations in Rock, Institute of Mining and Metallurgy, London, 1980.

2. Hendron, A. J., Jr., "Engineering of Rock Blasting on Civil Projects," from Structural and Geotechnical Mechanics, W. J. Hall (ed.), 1977

TABLE 1

COST ESTIMATE FOR TUNNEL STABILIZATION OPTION 1

Item	Quantity	Units	Unit Price	Price
1. Replacement of lagging	500	sf	6.00	$3,000
2. Steel Sets	22,100	lb.	1.50	33,150
3. Set 105-106 Repair	L.S.	-	-	2,000
4. Concrete and Grout	200	cy	400.00	80,000
5. Shotcrete on Steel Sets & Blocking	17	set	1000.00	17,000
6. Grading & Filling Surface Subsidence	L.S.	-	-	5,000
Subtotal 1				$140,150
7. Mob. & Demob.	L.S.	-	-	20,000
Subtotal 2				$160,150
Contingency @ 20% of Subtotal 2				32,030
TOTAL ESTIMATED COST				$192,180

TABLE 2

COST ESTIMATE FOR TUNNEL STABILIZATION OPTION 2

Item	Quantity	Units	Unit Price	Price
1. Concrete	100	cy	400	$40,000
2. Reinforcing Steel	19,000	lb.	0.50	9,500
3. Formwork and Falsework	L.S.	-	-	3,000
4. Void Probing from Ground Surface	L.S.	-	-	2,000
5. Void Filling	50	cy	150	7,500
6. Set 105-106 Repair	L.S.	-	-	1,000
7. Grading and Filling Surface Subsidence	L.S.	-	-	$ 2,000
Subtotal 1:				$65,000
8. Mob & Demob.	L.S.	-	-	$15,000
Subtotal 2				$80,000
9. Contingency @ 20% of Subtotal 2				$16,000
TOTAL ESTIMATED COST				$96,000

TABLE 3

COST ESTIMATE FOR TUNNEL STABILIZATION - OPTION 3

Item	Quanity	Units	Unit Price	Total Price
1. Excavating	3,100	cy	$ 20.00	$ 62,000
2. 2 in. Mesh Rein. Shotcrete	440	sy	45.00	19,800
3. 8 ft. Resin-grouted Rock Bolts	150	ea.	40.00	6,000
4. 20 ft. Cement-grouted Dowels	20	ea.	100.00	2,000
5. Soil Nailing Wall	1,600	sf	50.00	80,000
6. Set 105-106 Repair	L.S.	-	-	2,000
7. Steel Sets - Bays 183-187	6,500	lb.	3.00	19,500
8. Shotcrete on Steel Sets & Blocking	5	set	1000.00	5,000
Subtotal 1				$196,300
9. Mob. & Demob.	L.S.	-	-	30,000
Subtotal 2				$226,300
Contingency @ 20% of subtotal 2				45,260
TOTAL				$271,560